Vol. VI.] *Issued Quarterly. Single Numbers, 8/6 net.* [No. 22.
Subscription 31/6 net, per annum, post free. Volumes commence in JULY. Title and Index supplied with the APRIL number. Cases for Binding, 3/- net; or the Volume bound in Case on receipt of the four numbers, for 5/- net, post free.

GENERAL LIBRARY
DEC 24 1918
UNIV. OF MICH.

The British Journal of Surgery

UNDER THE DIRECTION OF THE FOLLOWING EDITORIAL COMMITTEE:

Sir BERKELEY G. A. MOYNIHAN, K.C.M.G., C.B. (Leeds), *Chairman.*

GEORGE E. ARMSTRONG (Montreal)
GILBERT BARLING, C.B. (Birmingham)
Sir WILLIAM BENNETT, K.C.V.O. (London)
JAMES BERRY (London)
FREDERIC F. BURGHARD, C.B. (London)
FRANCIS M. CAIRD (Edinburgh)
Sir W. WATSON CHEYNE, Bt., K.C.M.G., C.B., M.P. (London)
W. H. CLAYTON-GREENE (London)
HERBERT S. CLOGG (London)
EDRED M. CORNER (London)
Sir THOS. CRISP ENGLISH, K.C.M.G. (London)
CHARLES H. FAGGE (London)
Sir RICKMAN J. GODLEE, Bt., K.C.V.O. (London)
Sir A. PEARCE GOULD, K.C.V.O. (London)
W. SAMPSON HANDLEY (London)
RAYMOND JOHNSON (London)
Sir ROBERT JONES, C.B. (Liverpool)
Sir ALFRED H. KEOGH, G.C.B., G.C.V.O.
Sir WM. ARBUTHNOT LANE, Bt., C.B. (London)
Sir ALEXANDER MacCORMICK (Sydney)
Sir GEO. H. MAKINS, G.C.M.G., C.B. (London)
HENRY A. MOFFAT, D.S.O., (Capetown)
RUTHERFORD MORISON (Newcastle-on-Tyne)
Sir HENRY MORRIS, Bt. (London)
Sir THOMAS MYLES, C.B. (Dublin)
R. H. PARRY (Glasgow)
D'ARCY POWER (London)
SIDNEY W. F. RICHARDSON (Capetown)
JAMES SHERREN (London)
THOMAS SINCLAIR, C.B. (Belfast)
Lt.-Col. CECIL R. STEVENS (Calcutta)
Sir HAROLD J. STILES (Edinburgh)
EDWARD H. TAYLOR (Dublin)
J. LYNN THOMAS, C.E., C.M.G. (Cardiff)
HENRY ALEXIS THOMSON, C.M.G. (Edinburgh)
WILLIAM THORBURN, C.B. (Manchester)
GEORGE E. WAUGH (London)
W. I. de COURCY WHEELER (Dublin)

E. W. HEY GROVES (Bristol), *Editorial Secretary.*

OCTOBER, 1918

BRISTOL: JOHN WRIGHT & SONS LTD.
LONDON: STATIONERS' HALL COURT. SIMPKIN, MARSHALL, HAMILTON, KENT & CO. LTD.
TORONTO: THE MACMILLAN CO. OF CANADA LTD.
CALCUTTA: BUTTERWORTH & CO. (INDIA) LTD.; THACKER, SPINK, & CO. BOMBAY: THACKER & CO. LTD
MELBOURNE, SYDNEY, ADELAIDE, and BRISBANE: G. ROBERTSON & CO. PROPRIETARY LTD.
SYDNEY: ANGUS & ROBERTSON LTD. NEW ZEALAND: WHITCOMBE & TOMBS LTD.
UNITED STATES OF AMERICA: WILLIAM WOOD & CO., NEW YORK *Sole Agents*

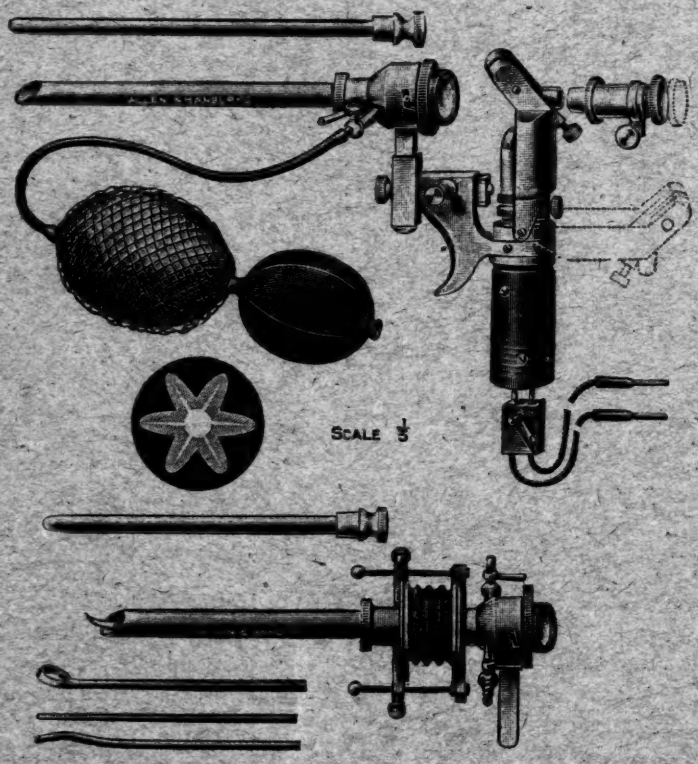
CONTENTS

	PAGE
Sir Benjamin Collins Brodie, Bart. (with Medal)	157
Bone Growth and Bone Repair — ARTHUR KEITH	160
Weight Extension in the Treatment of War Fractures — LIEUT. W. H. OGILVIE	166
The Diagnosis and Treatment of Injuries to the Crucial Ligaments — MAJOR S. ALWYN SMITH, D.S.O.	176
Affections of the Large Joints due to Gunshot Wounds: their Late Results and Treatment — S. W. DAW	190
Ununited Fractures, with Special Reference to Gunshot Injuries and the Use of Bone Grafting — ERNEST W. HEY GROVES	203
The Treatment of Disabilities of the Upper Extremity in Military Surgery — MAJOR NAUGHTON DUNN	248
Results of Primary Excision for Wounds of the Elbow-Joint — CAPT. A. EISDELL MOORE	265
The Structure, Forms, and Conditions of the Ends of Divided Nerves — MAJOR EDRED M. CORNER	273
Injuries of the Peripheral Nerves from the Surgical Standpoint — MAJOR H. S. SOUTTAR AND CAPT. E. W. TWINING	279
Suture of the Musculospiral Nerve: Three Cases — CAPT. GWYNNE WILLIAMS	315
Some Notes on Operative Procedure in Nerve Injuries — ROBERT KENNEDY	317
Short Notes of Rare or Obscure Cases	
A Case of Gunshot Injury of Meckel's Diverticulum — MAJOR GORDON TAYLOR	324
Congenital Defect of the Thorax, with Sprengel's Deformity — CAPT. HAROLD BURROWS	325
A Case of Torsion of the Appendix — JOHN E. PAYNE	327
Reviews and Notices of Books	328

ALLEN & HANBURYS LIMITED, LONDON.

AERO OPERATING URETHROSCOPE.

WYNDHAM POWELL'S LATEST MODEL.



Made under the supervision of Mr. Wyndham Powell.

Descriptive Circular on application.

ALLEN & HANBURYS LTD. Manufacturers of Surgical Instruments and Appliances,

48, WIGMORE STREET, LONDON, W.1. Works: Bethnal Green, E.2.

SIR BENJAMIN COLLINS BRODIE, BART.

1783–1862.

FEW gentlemen were attracted to surgery in the days which preceded the introduction of anæsthesia. The training was rough, the physical toil was great, and the mental strain was apt to be overwhelming when a prolonged operation was performed upon a conscious patient. It is no wonder, therefore, that members of the better educated families with a bias towards medicine chose to become physicians rather than surgeons.

Benjamin Brodie was an exception to the rule. He was the fourth child of an Oxford graduate holding the living of Winterslow, in Wiltshire; his mother was the daughter of a banker at Salisbury. From his father he inherited the clear common-sense which characterized him through life; from his mother the business instinct which made him careful in all his money matters without being penurious, for as a member of a large family he learnt early that he must make his way in the world by his own exertions. He was, however, fortunate in his relations, both in law and in medicine. Dr. Denman, the accoucheur, had married his aunt; Sir Richard Croft, equally successful in the same branch of practice, had married a cousin; Dr. Baillie, nephew of William and John Hunter, had married another cousin; Dr. Denman's son, Brodie's cousin, afterwards became Lord Chief Justice, and was well known as one of the advocates at the trial of Queen Caroline; whilst Peter Brodie, his eldest brother, held a high position as a conveyancer.

Brodie was educated privately by his father, and obtained a thorough grounding in Greek, Latin, and mathematics, until he was sent to London in 1801 to study medicine. In the autumn of that year he attended the anatomical lectures given by Abernethy at St. Bartholomew's Hospital and by James Wilson at the Great Windmill Street School of Medicine—for as yet there was no organized medical teaching at the London hospitals, and it was allowable for any student to attend a course on payment of a fee to the lecturer. At the Great Windmill Street School he soon found opportunities to act as demonstrator, and to give occasional lectures in the absence of the recognized teachers. In this way he made his mark, and he maintained his relationship with the School until long after he was well established as a successful surgeon.

In the meantime he did not neglect his social advantages. He was admitted a member of 'The Academical Society,' a small body meeting for the discussion of literary subjects at a house in Bell Yard. Dr. Maton was President, Lord Glenelg and his brother, Bowdler, Dr. Bateman, Sir Henry Ellis, and Lord Chief Justice Cockburn being amongst the members. In 1803 Brodie became a pupil of Everard Home—brother-in-law of John Hunter and surgeon to St. George's Hospital. He studied surgery at this hospital, and from May until November, 1805, he held the office of house surgeon. At the end of this short term of office Everard Home invited him to act as his assistant at operations, and he thus gained an insight into private surgical practice. For the next two years and a half he lived in lodgings in Sackville Street, Piccadilly, without thinking it worth while to put up a doorplate. During this time he revolutionized the clinical teaching at St. George's Hospital, for, living within easy reach of the Hospital, being young, and having little private practice, he was able to devote both time and energy to his hospital duties. He was, besides, fond of teaching, and made it an especial point that the students should make careful notes of their cases, even as he did himself. He also assisted Home in the researches with which he was occupied at the Hunterian collection upon various subjects of comparative anatomy, and he thus became acquainted with Clift, the conservator of

the museum in which the collection was housed at the Royal College of Surgeons in Lincoln's Inn Fields. He was also introduced to Sir Joseph Banks—the President of the Royal Society—who speedily conceived an affection for the well-educated and modest young surgeon, of whose attainments he must have received an excellent account from many sources. Banks invited him to his Sunday evening meetings, and occasionally to dine, and at these gatherings Brodie met all that was best in the social and scientific society of the day. Brodie became assistant surgeon at St. George's Hospital in March, 1808, at the early age of twenty-five, on the nomination of Keate and Home, two of the surgeons, Gunning, the third surgeon, being absent on service in the Peninsular War, and for the next four years Brodie acted as full surgeon, in conjunction with Robert Keate, the other assistant surgeon, although it was not until 1822 that he succeeded officially to the post of full surgeon. On becoming assistant surgeon, Brodie began to deliver lectures upon patients, of the kind now called clinical lectures, in contradistinction to the systematic lectures given by other surgeons and teachers of surgery in London.

In 1809 he took a house in Sackville Street, furnished it with money borrowed from his mother, and began to practise privately. He was elected a Fellow of the Royal Society in 1810, gave the Croonian Lecture *On the Effects Produced by certain Vegetable Poisons*, and was awarded the Copley Medal in 1811, being then only twenty-eight years of age. In the spring of 1812 Mr. Wilson wished to retire from the management of the Great Windmill Street School of Medicine, and proposed that Brodie should acquire the house, the museum, and the goodwill upon payment of £7000. Brodie had neither the money nor the inclination to devote himself entirely to teaching, and the school was afterwards purchased by Sir Charles Bell. In 1816 he married the third daughter of Mr. Serjeant Sellon, she being nineteen and he thirty-three, his income at the time amounting to £1530 from all sources. Three children of this marriage survived their parents. In 1819 he judged that his position had improved sufficiently to justify him in taking a larger house, and he moved accordingly to Savile Row. His work on *Diseases of the Joints* drew him into notice as a surgeon, and from this time onwards his advancement was rapid and uninterrupted, until he rivalled the position which had been attained by Sir Astley Cooper.

In 1819 he succeeded William Lawrence as Professor of Comparative Anatomy and Physiology at the Royal College of Surgeons, holding the post until 1823. In 1821 he was first summoned to Court to attend King George IV, at the time when Sir Astley Cooper removed a sebaceous cyst from the scalp. His attentions were so far appreciated that in 1828, when Sir Astley Cooper was appointed Serjeant Surgeon, Brodie was gazetted as Surgeon to His Majesty's person, and in 1830 he was in constant attendance at Windsor during the King's last illness. In 1832 he was appointed Serjeant Surgeon by King William IV, in succession to Sir Everard Home. Two years later, following a custom dating from the union of the Barbers' Company with the fraternity of Surgeons in 1540, Brodie as Serjeant Surgeon was admitted, on the occasion of the first vacancy, a Member of the Council of the Royal College of Surgeons of England and a member of the Court of Examiners. In 1834 he was raised to the rank of a baronet, and two years later he bought Broome Park in one of the prettiest parts of Surrey. He was elected President of the Royal College of Surgeons of England in 1844, and was chosen the first President of the General Medical Council in 1858. In the same year he achieved the crowning wish of his heart, for he became President of the Royal Society. For some time before his death he suffered from double cataract, for the relief of which he was operated upon by Sir William Bowman. He died at Broome Park on October 21, 1862, full of years and honour.

Brodie was noteworthy in several different aspects. As an educated gentleman, he filled with great distinction the exacting position of President of the Royal Society, and published a series of dialogues to which he gave the name of *Psychological Inquiries*, dealing with the mutual relations of physical organization and the mental faculties.

As a scientific man, it is interesting to note that although he taught anatomy, his main interests, when surgery was based on anatomy, were upon the physiological side.

MEDAL PRESENTED TO SIR BENJAMIN BRODIE BY HIS FORMER PUPILS AT ST. GEORGE'S HOSPITAL.

As a surgeon, his *Pathological and Surgical Observations on the Diseases of the Joints* was the first serious attempt to separate the various conditions which had been previously classed together as 'white swelling.' The grouping was purely clinical, for as yet the microscope had not come into use in surgery. In reading the cases which he records, it is noteworthy that a large number were cases of hysterical joints occurring in young women of the upper classes as a direct outcome of the faulty system of education and hygiene then in vogue; whilst it is to the credit of Brodie that he recognized the value of movement —or, rather, the harmful effects of prolonged rest—on slightly-inflamed joints. In disease of the breast he drew attention to the serocystic sarcoma, which is still called Brodie's tumour. Next to diseases of the joints, he appears to have been most interested in stricture and other surgical diseases of the urinary organs, and by precept and example he recommended lithotrity in preference to lithotomy. Brodie's surgical work was throughout more diagnostic than operative. He performed such operations as were necessary, but it is evident that the manipulative side of surgery did not attract him.

As a medical reformer, Brodie took a leading part in that re-modelling of the surgical side of the profession in England which resulted from the establishment of the new order of Fellows of the Royal College of Surgeons by the Charter of 1843. This charter, for good or for evil, took away all initiative power from the Members and gave it to the Fellows, by whom alone the governing body was elected. Previous to this charter the governing body, or Court of Assistants as it was called, had co-opted its members, who held office for life, a practice which had been continued from the times of the United Company of Barber Surgeons, for at no time had the general body of members exercised any selective right. The charter abolished several obvious abuses, such as the retention of office for life by the examiners and members of Council, and the limitation of the offices of President and Vice-President to the members of the Court of Examiners.

The medal illustrating this article was presented to Sir Benjamin Brodie in 1840 when he retired from office as surgeon to St. George's Hospital. The presentation was made on behalf of his pupils and medical friends as a testimony of their gratitude for the manner in which he had performed all the duties connected with that institution. Lady Brodie always considered the likeness to be particularly happy. There is a bronze replica in the Board Room at St. George's Hospital. The present reproduction is made from a plate in the possession of the Royal Society of Medicine.

BONE GROWTH AND BONE REPAIR.*

By Professor ARTHUR KEITH, F.R.S.

LECTURE III.

RESEARCHES INTO BONE GROWTH AND BONE REPRODUCTION BY OLLIER OF LYONS AND MACEWEN OF GLASGOW.

In almost the selfsame year that Goodsir of Edinburgh was quietly establishing to his own satisfaction that bone corpuscles were the agents which built bones up and took them down, Marie Jean-Pierre Flourens, the permanent secretary of the Academy of Science of Paris, was proving not only to his own satisfaction, but to that of all the world, that Duhamel was right: periosteum was the maternal tissue of bone. When he published his "Recherches sur le Développement des Os et des Dents," in 1842, he was a man of forty-eight, with behind him the most brilliant record of experimental success of any man in Europe. He had that gift which is often given to Frenchmen—a clear incisive engaging style which carries conviction with every sentence. He had repeated and extended Duhamel's observations. Duhamel was right: new bone was deposited on the surface of the bone under and by the periosteum. Hunter was right: absorption of bone was continually taking place; the substance of every living bone was in a constant state of flux. He had destroyed, as Troja had done, the medulla and medullary lining of a long bone, and seen the whole shaft die and the periosteum start into active life and lay down a new shaft. He emphasized the fact that growth in length took place at the epiphyseal lines. People knew of the discoveries of Flourens; those of Goodsir were overlooked.

In 1857 Flourens was ageing rapidly, when a young medical graduate of Monpellier, of the name of Louis Ollier, came to Paris, attracted above all by the great name of Claude Bernard, the genius of experimental research. Ollier was a son of south France; although a graduate of Monpellier, his real University was Lyons; there he had studied under Bonnet, the leading authority of that time on diseases of the joints. In his student days the functions of the periosteum had been debated; Ollier held the opinion that it had no osteogenetic function—in spite of the researches of Duhamel and Flourens. During the short period which he spent in Paris he determined to settle the matter for himself by applying the experimental method of Claude Bernard. He went to work in the laboratory of Chauveau. He selected a young rabbit as the subject of his first experiment. He lifted from the subcutaneous surface of the tibia a tongue-shaped flap of periosteum, leaving it attached by its base. He turned the flap or strip over the deep flexor muscles of the leg so that it formed a kind of annular ligament over them. In six weeks he found that the membrane had become a loop of bone, thick and strong at its base, but tapering towards the tip until it became fibrous. He repeated the experiment in a slightly different form and got the same result; a semi-detached piece of periosteum could form bone. He then proceeded to vary the conditions of his experiment further. He twisted the base of the periosteal flap so that the vessels entering at its base would be compressed. The twisted slip of periosteum produced a beaded string of bony nodules. In a further experiment he raised a process of periosteum, turning it, as before, over the adjoining muscles. Three days later he detached its base from the shaft of the tibia. The detached slip produced bone. He then raised, and at the same time completely detached, a piece

* Three lectures of a course on "The Anatomical and Physiological Principles underlying the Treatment of Injuries to Muscles, Joints, and Bones," delivered at the Royal College of Surgeons, England.

of periosteum, and transplanted it into the subcutaneous tissue of the thigh. He used, for the first time, periosteum as a graft; that graft produced bone. Ollier entered Chauveau's laboratory in Paris a sceptic; when he completed his first series of experiments he was convinced of the osteogenetic properties of periosteum.

We must look closely at Ollier, because he is almost the earliest example we shall meet of a new type of surgeon—one who realized that experimental physiology is, and must be, the basis of all rational operations in surgery. Lister and he were almost contemporaries; Ollier was born in 1830, three years after Lister. Lister gave the first ten years of his career to experimental physiology; so did Ollier. The series of experiments we have just narrated—done when Ollier was in his twenty-eighth year—would have satisfied most young men. Ollier had the qualities of the true investigator: he realized that his experiments had touched only the fringe of the physiology of bone. Hence, when he returned to Lyons in 1859, where he was soon to be called to fill the chair of clinical surgery and serve as surgeon to the Hôtel-Dieu, he continued his investigations year after year until in 1868 he published the results of his experimental and clinical observations in two volumes under the title of "Traité Expérimental et Clinique de la Régénération des Os et de la Production Artificielle du Tissu Osseux." From the time he obtained his first results Ollier had one major object in view—namely, to prove that, after resection of a joint, restoration of the articular ends of the bones was only possible if the operation had been conducted so as to save the periosteum.

When he commenced a second series of experiments in 1858, he devoted his attention more closely to the appearance and structure of the periosteum. Critics had alleged, when he raised the periosteum—which he did by pressing a rugine firmly against the surface of the shaft of the bone—that he also detached fragments of bony matter, and it was these and not the periosteum which gave rise to new bone. He therefore examined with a lens his detached strips of periosteum, and satisfied himself that they were free from visible fragments of bone. He was a proficient microscopist, and studied the minute structure of the periosteum. He defined that membrane as including all the soft tissue which covers the surface of a living bone. When a section of periosteum was studied, as seen on the surface of a growing bone, he could observe a gradual transition of structure from its superficial to its deep surface. As its deepest stratum approached the bone, he observed that it became more cellular in structure, and where it actually mingled with the bone, that these cells were clearly of the bone-forming type—they were osteoblasts. Osteoblasts, he found, were present in the deepest stratum of the periosteum; its deepest layer formed an osteogenetic tissue. It was true, he said, that these osteoblastic cells were sparsely scattered in the deepest stratum of the periosteum of an adult animal, but he also demonstrated that they could be quickly increased in number by irritating a bone by injury.

So he again resorted to his 'flap' experiments. He scraped the deep surface of such tongue-shaped strips of periosteum with his knife, and the soft juicy matter thus collected was transplanted to a living subcutaneous bed; from the matter thus transplanted fine granules of bone were formed. He had thus proved, at least he thought he had, that the deepest stratum of the periosteum had an osteogenetic function. Raising the tongue-shaped flaps from the periosteum of the tibia, he destroyed the deep or osteogenetic layer of one part of it by scraping or by applying a cauterizing fluid, while in the remaining area of the flap the deep layer was left uninjured. On turning such a flap over a muscular bed, he observed that only the intact or uninjured area produced bone. That was, in Ollier's estimation, another proof that the deep stratum of the periosteum produced bone.

Then followed a series of experiments in which he completely detached flaps of periosteum and transplanted them as grafts—heterotopic grafts, he called such slips—to other parts of the body, where they held and produced bone. He found that the success of such grafts depended on many circumstances. There was, in the first place, the occurrence of suppuration. Suppuration, he found, could kill part of a graft and leave another part unaffected; much of Ollier's work is invalidated because he did not know the cause and effects of suppuration. Grafts from young animals took more readily than those from adult animals. Those from the shafts of long bones held better than those from flat bones.

Periosteal grafts of the rabbits had a greater power of reproduction than those of cats. The power varied with the bone ; a periosteal graft from the nasal bone of the cat would hold, while that from the corresponding bone of the rabbit would fail. He showed that the dura mater had a greater osteogenetic power, when transplanted, than the pericranium. All of these results represent real additions to our knowledge of bone life.

Having thus completed his researches on the periosteum, and satisfied himself that it possessed an osteogenetic power to a high degree, Ollier turned his attention to the marrow. He tied the nutrient artery to see if the main arterial supply was necessary for the life and sustenance of the marrow; he found that ligature made no apparent difference. He failed to raise grafts of bone from transplanted marrow. But he observed that he could increase its osteogenetic power by irritating the bone by injury. To test its osteogenetic power in another way, he introduced a new kind of experiment. He amputated the foot and lower part of the leg of a rabbit, and into the medullary cavity of the tibia thus exposed he introduced an open metallic tube. At the end of a month he found that the tube was filled with ossifying granulation tissue ; that tissue, he concluded, was produced by the marrow, and therefore marrow did possess an osteogenetic power in a low degree.

Having thus tested the powers of periosteum and marrow to form bone, he now passed to bone itself. He found that a piece of bone, detached from periosteum and medulla, could not serve as a graft ; it died, and ultimately became absorbed. It acted amongst living tissues as a foreign body. One would be inclined to suppose that Ollier's experiments on the transplantation of bone fragments had been vitiated by sepsis, did he not go on to describe experiments where such grafts held when they were transplanted with periosteum and marrow still attached to them. In his opinion, pieces of living bone with their periosteum and marrow still intact provided the most perfect form of bone graft ; he supposed that the periosteum served as an intermediary between the bone fragment and the muscle in which it had been implanted. Yet Ollier knew that the shaft of the tibia of a young animal could be completely denuded of periosteum and its marrow entirely removed, and yet live and grow. The results thus obtained confirmed his belief that periosteum was the chief bone-producing tissue.

Ollier made experimental fractures ; the conclusions he drew from them were : (1) The periosteum is the chief agent in forming the callus ; (2) The marrow takes a slight part ; (3) The bone itself takes the least share.

He opened up another new subject when he began to study the effects of experiment on epiphyseal lines of growth. He observed that irritation of the shaft of a bone, by injury, could increase the rate of growth at these lines. Such a result tells one as plainly as can be that there is a mechanism in every bone for correlating the activity of its army of living cells—bone-laying and blood-carrying cells. He discovered that the epiphyseal disc of cartilage could keep up a continuous supply of material for increasing the length of a bone only when it formed an intrinsic part of that bone. When the disc was cut out and transplanted, its growth failed ; it became a disc of bone. It was known before Ollier's time that in every long bone there is an epiphyseal disc of 'maximum growth'—a disc at which the major part of the length of a shaft is produced. The maximal discs for the femur and tibia lie respectively above and below the knee-joint, whereas those for the humerus and radius are placed at the shoulder and at the wrist. Ollier was the first to study experimentally the exact shares taken by the proximal and distal epiphyses in producing the growth of a bone in length.

It is unnecessary here to enter into three other series of experiments carried out by Ollier. He repeated Duhamel's experiments of boring holes in the shafts of growing bones to make certain that growth in length took place only at the epiphyseal lines. In another series he repeated, and extended in great variety, the kind of experiment carried out by Syme—the excision of the shafts of long bones, or parts of a shaft, to discover the share taken by the periosteum in the reproduction of new bone. His conclusion was that the periosteum was the all-important factor ; the surgeon must preserve it when he performed a resection if he would hope for a reproduction of the bony parts which were being excised.

Then there was a third, and in Ollier's opinion the most important, series—those in which he studied the reproduction of joints. His main conclusion one could guess—resections of joints must be performed so that the periosteum covering the excised parts was preserved. He found cartilage to be the most inert, the least endowed with the powers of vitality and reproduction, of all the tissues of the body. On only one occasion did he find a transplanted piece of epiphyseal cartilage produce bone ; he never did see articular cartilage reproduced within a new articulation.

So far we have been following Ollier as an experimental physiologist ; we have time merely to glance at one of his clinical cases—the shoulder-scarred little maid so beautifully portrayed in *Plate VIII* of Vol. II of his treatise. Her name was Louise Gaillard ; she came under Ollier's care in September, 1864, a meagre tuberculous child of five, with suppuration of the shoulder and arm. Ollier removed the upper half of the diseased but living humerus—head, neck, and shaft—by his subperiosteal method. The bone was reproduced. In the following year, 1865, Louise was able to work in a cigarette factory, and a year later, when she was seven, the restored humerus was only 46 mm. shorter than its normal companion. This is one of the classical cases of resection of the humerus. We have noted several others—Charles White's case of 1768, and Syme's case of 1826, and there is another, a resection of the humerus by Hunter. There is also a fifth and yet more famous case which we shall examine in a subsequent part of this lecture.

We shall see presently that Ollier made a grave blunder in the course of his experiments. But when we have made that admission, we have to recognize him as the man who established the evidence on which the principles of bone surgery must be founded. It was he who gave orthopædic surgeons materials for framing a rational charter. The total result of his ten years' investigations was to make him a confirmed Duhamelite—a worshipper of periosteum. We take our leave of Ollier of Lyons with the completion of his great *Treatise* in 1868 ; he was destined to see the commencement of the twentieth century and his labours fully recognized by a new generation of surgeons.

We are now to return to Glasgow. The occasion of our former visit to that city was in 1877, when William Macewen, then aged 29, introduced a new operation for the cure of knock-knee. At the same time he was rectifying the bent tibia of rickety children by the excision of wedge-shaped pieces. In the following year, 1878, a boy, three years of age, was brought to him at the Glasgow Infirmary, emaciated and exhausted from suppuration following acute osteomyelitis of the right humerus. Almost the entire shaft of the bone was dead ; after resection had been performed, there remained in the boy's arm only the extremities of the humerus, the lower being represented merely by the epiphysis, while the upper was made up of the epiphysis and a small part of the shaft. In 1880 the boy was brought back by his parents to have his arm amputated ; it was useless, although the muscles were healthy and could act. No part of the humeral shaft had been reproduced. Making a longitudinal incision deep into the outer aspect of the arm, Macewen planted along the muscular furrow thus opened out a row of tibial grafts. They were pieces obtained by fracturing wedges which had been cut from the bent tibiæ of various boys. Most of these grafts were devoid of periosteum, yet they held and lived. As thus reconstructed the boy's humerus was six inches in length, being made up of three elements : $4\frac{1}{4}$ in. (10·7 cm.) of the shaft, composed of tibial grafts ; the upper part, $1\frac{3}{4}$ in. (4·3 c.m.), derived from the original upper extremity ; and there was also the persistent lower epiphysis. In 1910, when the boy had become a capable workman of 35, he had a useful, well-modelled, if curved, humerus, which measured 11 in., being 3 in. shorter than the normal bone of the left arm. If Ollier's researches had revealed the full truth, then those broken tibial fragments ought to have died and been absorbed ; and yet there can be no doubt they had lived, and given rise to a shaft which had become connected with the persistent upper and lower extremities, and thus become parts of a functional humerus. When he sowed the grafts, Macewen could not have missed noting any ossifications which had survived from the old periosteum. No such ossifications were present. By this operation Macewen demonstrated, for the first time, that fragments of bone may be used as grafts, and that such grafts will live, grow, and reproduce bone. Further, that the

bone reproduced by such grafts can, under tensions and stresses brought to bear on them by the muscles of the part, be moulded to form a real humerus—real in an anatomical as well as in a physiological sense. Macewen's case forms the fifth and greatest of a classical group of famous clinical humeri.

At the time when Macewen was employing bone grafts with great success in Glasgow, Ollier's opinions were in the ascendant in the rest of the world. At first the significance of Macewen's discovery and practice was not generally appreciated, nor was it later. Hence, fully thirty years after he had begun to use fragments of bone as grafts, Macewen, in order to force the truth of his discovery on the attention of surgeons, carried out a series of operations on animals.* He repeated Syme's experiments; he cut out, subperiosteally, $1\frac{3}{4}$ in. from a young dog's radius. At the end of four weeks there was still a gap in the bone; the periosteum had failed to form the missing part of the shaft. He then, in another animal, cut out the whole radius, leaving the periosteum in place; the periosteum again failed to reproduce bone. He carried out modifications of Ollier's experiments, raising flaps of periosteum from a young dog's radius, folding it round adjacent muscles of the foreleg. Both of his Ollierian flaps of periosteum failed to produce bone. He transplanted grafts of periosteum as Ollier had done, yet failed to succeed in raising bone from them. At first sight it almost looks as if the dogs of Edinburgh and Lyons were provided with a different kind of periosteum to that produced by dogs in Glasgow—in such sharp contrast stand the results of the experimenters of these cities. Yet all three surgeons are equally credible witnesses. There is only one explanation of their discrepant results: Syme and Ollier must have removed the soft tissues which cover bone to a greater depth than did Macewen. The evidence that periosteum, as usually raised by surgeons from the surface of the bones of a growing animal, does produce bone is so positive, so unassailable, that it cannot be rejected because a certain series of experiments gave negative results.

In order to study the effect of periosteum on the growth and life of a bone, Macewen removed this membrane from the radius of a young dog. He found, as Ollier had done, that the bone lived and that its growth was slightly retarded. The shaft lost its smooth contour. On such denuded bone he applied modifications of Duhamel's ring experiment; the rings became embedded in the shaft of the bone although the periosteum had been cut away

He carried out a series of experiments of a new kind to substantiate his clinical observations—namely, that bone itself could be grafted. He took two dogs, cut an inch out of a radius of each, removed the periosteum from the pieces excised, and broke each of these into fragments. He re-implanted the pieces so that the two dogs exchanged their radial fragments. The grafts held, and complete restoration of the radial shafts resulted. He took two other dogs, and exchanged the right radius of the one for the corresponding bone of the other. In each case the radius was stripped of its periosteum; yet the transposed bones lived, and became thicker than their untransplanted counterparts. He found that bone shavings, but not bone dust, served well as grafts; the greater the superficies of a fragment, the better he found it to serve as a graft. The greater the surface of the graft, the greater the area for nourishment and reproduction.

One cannot but admire Macewen's resource in devising experiments. We have seen that Ollier inserted metallic tubes within the medullary cavity to test the power of marrow to reproduce bone. Macewen used glass tubes, not to test the growth of marrow, but to exclude the periosteum from taking any part in filling up the gap resulting from the excision of a segment from the shaft of a bone. Having cut out a segment, he inserted in its place an open glass tube, so that the open ends of the tube faced the cut ends of the shaft. The tube became filled from the shaft with growing tissue which ossified. The new bone thus formed came from the shaft; it could not have come from the periosteum. He conceived it possible that an absorbable ferrule placed round the adjacent ends of a broken

---

* *The Growth of Bone; Observations on Osteogenesis*, Glasgow, 1912.

bone might accelerate union by serving to confine the repairing exudate. Such a tube took the place of the periosteum, which Macewen regarded as a 'limiting' membrane.

We do not suppose that the briefly-narrated researches of John Goodsir were known to Sir William Macewen when he carried out these experiments; yet his definition of the function of the periosteum, as a membrane to limit the excursions of the osteoblast to prevent bone-building cells from invading surrounding tissues, is an exact replica of John Goodsir's conception. The dissecting-room and laboratory observations which Goodsir made in the fifth decade of the nineteenth century led him to formulate exactly the same conception of bone growth as Macewen arrived at seventy years later from a life of active clinical and experimental observation. Macewen, however, has much better evidence of the limiting function of the periosteum to lay before us than had Goodsir. He cites evidence from a case where osteoblasts had been carried within an aneurysmal sac and set up ossification in the fibrinous walls; he describes cases where the exudate from fractured surfaces has been disseminated by massage into the surrounding ruptured muscles, where it formed a mass of ossific tissue; he cites instances of fractures where the periosteum has been much torn, thus permitting osteoblasts to escape into the surrounding tissues and form bone. He alludes to cases where the periosteum has fallen between the broken ends of bones and prevented union. He thus gives a logical explanation of Hunter's observation that the periosteum or tissues which surround a broken or diseased bone may take on an 'ossific disposition.'

There is another series of Macewen's experiments to which we must allude before we leave his work. We have seen that Ollier studied the epiphyseal discs of growth. Macewen rightly protests that such discs have nothing to do with epiphyses; the epiphysis has its own peculiar independent nature. The growth disc is part of the shaft—of the diaphysis—and therefore ought to be called the diaphyseal disc, or shaft-disc. It is solely concerned, as he has demonstrated, with the growth of the shaft. He removed the shaft of the radius from a young dog, leaving merely the epiphyses and diaphyseal discs. In six weeks the shaft was reproduced, not from the periosteum, but from the diaphyseal discs. The point of meeting between the parts of the shaft produced from the proximal and distal discs could still be seen in the restored radius. To make certain his interpretation was right, he removed 2½ in. from the shaft of a growing dog's radius, and covered each cut end with a metal cap. In seven weeks the caps had met. He removed the distal third of the shaft of a radius, including the epiphysis; he found, as Ollier had done, that the part excised was reproduced with an epiphysis, but there was a degree of shortening. Ollier believed reproduction in such cases of excision was done from the periosteum; Macewen shows it is done by growth of the shaft in length. The idea that compensatory growth at the diaphyseal discs may be utilized by surgeons to make good an extensive gap in the shaft of a bone is a discovery we owe to Macewen.

Macewen's work brings us down to the position of our knowledge regarding the growth and reproduction of bone at the present day. We have seen Duhamelites and Hallerites come into existence in the eighteenth century; we have seen them in the persons of Syme and Goodsir in the nineteenth century; and here we are in the twentieth century still with the same two sects—those who regard periosteum as the chief osteogenetic element of the human skeleton, and those who regard bone itself as that element. Where is the truth? As in most cases of this kind, there is truth on both sides, but the greater share is on Macewen's. My interpretation of his work is this. Orthopædic surgeons lay it down as a basal principle that a deformity, to be remedied, has first to be over-corrected. That is what I think Macewen has done. His has been a great practical service; he has given bone its rightful place among the living tissues of the body—a tissue which has the power to reproduce itself. But in raising bone to its proper biological and surgical status, he has been less than just to periosteum. Periosteum can reproduce bone, for no one has yet made a microscopical examination of the periosteum of growing or of inflamed bone and failed to find in it those very elements which Macewen admits to be the creators of bone—osteoblasts. From an anatomical, and I think also from a surgical, point of view, the osteogenetic power of the deepest stratum of the periosteum cannot be denied.

WEIGHT EXTENSION IN THE TREATMENT OF WAR FRACTURES.

By Lieutenant W. H. OGILVIE, R.A.M.C. (T.C.)

During two and a half years' work at the Urgency Cases Hospital, I was enabled, through the kindness of my chief, Mr. Cairns Forsyth, to see a great deal of the methods and apparatus used in the treatment of war fractures in the French army, both at the hospitals round us in the 'zones des armées,' and at the Paris base hospitals. I had also the opportunity, while on leave, of seeing something of British methods. During the same period the care of several thousand patients, of whom the majority were cases of war fractures or injuries of joints, enabled me to compare the value of the different methods by the only real test, that of personal experience, and to evolve a line of treatment which gave the most satisfactory results. Such a system was in no part original, but compounded from the ideas of a great many people—and chiefly from those of Dr. Blake, of New York City, whose wards I was privileged to visit at Neuilly in 1915 and at Ris Orangis in 1916; yet it was the logical outcome of a few simple principles, chiefly those of suspension and weight extension, to which all experience seems to point, and yet which are by no means universally admitted.

On transferring to the R.A.M.C. in October, 1917, I found that the conclusions to which I had been led differed in so many points from British practice as I saw it, that I considered it worth while to set down in writing for my friends on the surgical division an account of the methods we had been using and of the principles underlying them. While any such detailed account of methods and apparatus is of small practical value unless backed by results, a consideration from an outside point of view of the general principles involved in the treatment of fractures is perhaps of enough interest to those working at this subject to warrant its publication.

The fractures seen in war differ from those occurring in civil life in respect of their causal agent, the nature of the injury inflicted, and the methods of treatment applicable for their repair.

Causal Agent.—War fractures are caused by a small heavy projectile travelling at an enormous velocity, which as a rule penetrates the whole limb, and fractures the bone by actually passing through its substance. Civil fractures are usually caused by some considerable force acting with much less suddenness upon the limb as a whole, and breaking the bone by force transmitted through the soft tissues. The practical results of this difference in the manner of infliction of the fracture are as follows:—

Nature of Injury.—1. Civil fractures are often transverse or oblique. Where there is comminution, this is not usually excessive; the bony fragments are moderate in number and of appreciable size. Moreover, the fragments retain part at any rate of their attachments and blood supply, and are not far displaced from their normal position. It would be theoretically possible, by dovetailing the pieces together, to restore the original form of the bone. War fractures, on the other hand, are usually comminuted. The comminution is perhaps more local than that caused by indirect violence, but is far more complete. The fragments are of all sizes, down to mere bone dust. Many of them have lost their viability owing to direct injury, or have been torn away from their blood supply; they have often been transported far from their normal position, or even blown right out of the limb. The important thing is that in the former class it is often possible by traction and manipulation to 'set' the fracture, so that there is some tendency for the fragments to remain in position if suitably supported. In war fractures there is no question of restoring the original shape of the bone, and the broken ends, even if brought into correct position, have no such tendency to interlock.

2. A similar condition is found in the case of the natural splints of an injured bone—the muscles taking origin from it, inserted into it, or lying along it. In a war wound, those lying in the path of the missile have been completely destroyed, and when the fracture has been put into position, their support is no longer available to keep it there.

3. Civil fractures are often simple. When compound, infection is not certain, and may be of a very mild order. But every war wound must be treated as potentially the seat of a virulent infection, for the high-speed projectile leaves a track lined with killed tissues on which any bacteria present can flourish. Again, in a war fracture, the wound necessarily communicates with the fracture, and infected material has passed through the bone itself. In civil practice an infected wound may coincide with an uninfected fracture. Therefore, while in an accidental fracture the claims of dressing may often give way to those of splinting, in a war fracture the wound is a question of life, and the treatment of the fracture a question of secondary urgency. Thus, no apparatus is permissible which does not allow free inspection of the wound and ready access for dressing.

Treatment.—It follows that a method suitable for the treatment of a war fracture must satisfy the following requirements. Fixation must be continuous until union has commenced. It must at the same time leave the wound (and therefore necessarily the seat of fracture) accessible for frequent and extensive dressings, and also allow ready inspection of the limb on either side of the injury. It must be possible for this dressing and inspection to be carried out without interfering at all with the fixation of the fracture.

All forms of splint moulded to the limb, or retaining position by pressing on the bone at or near the seat of fracture, are therefore out of court. Only two methods satisfy the requirements: (1) Direct fixation of the fractured bone itself by plates, wires, or pegs; (2) Continuous traction on the fractured segment from points outside the injured area. The severity of the infection found in the wounds, and the invariable implication of the bone itself in this infection, forbid the first method. Some form of traction, then, is the only one which will at the same time allow continuous fixation and ready accessibility.

The traction may be effected in two ways: (1) By *counter-extension* against some part of the skin surface, this surface being usually at the insertion of the limb into the trunk; and (2) By *extension with weights* running over pulleys, using the mass of the body as the force against which the extension is made.

1. COUNTER-EXTENSION.

This principle is the one by far the most commonly employed at present, and is exemplified in the Thomas knee and arm splints, and in the Robert Jones humerus splint. It has, however, the following serious disadvantages:—

1. The natural place from which to take counter-pressure is at the junction of the limb with the trunk. This situation has many drawbacks, none the less real because they can to a large extent be overcome by care and ingenuity: (*a*) There is a danger of pressure on the main vessels and nerves (this is greater in the case of the axilla than of the groin); (*b*) Where there is no such serious pressure as this, there is none the less a liability to congestion in the limb distal to the ring, and during the acute stage of infection passive congestion is an unmixed evil; (*c*) Perspiration in the axilla, and excreta in the case of the perineum, make it difficult to keep the skin in good condition.

2. It is very hard to make any skin surface take continuously the pressure that is required to make *certain* of correct length, because of the liability of the skin area to slough. For example, in the case of a fractured femur, a pull of 20 lb. is often required initially; at the lowest rate one of 15 lb. must be exerted for the first three weeks. The skin of the buttock and perineum cannot stand anything like this amount of pressure continuously.

3. The ring is always a hindrance to proper inspection. In the case of a high fracture it also interferes with adequate attention to the wound.

4. The amount of extension applied is guessed, not known. This is unscientific.

5. Traction is never steady; even if its average strength is correct, it will at one

time be excessive, at another insufficient; both extremes are harmful. In the case of the Thomas knee-splint applied to the lower limb, a very slight amount of flexion or of abduction will lengthen the distance between the two fixed points by half an inch, and largely nullify the extension.

The exact control of the extending force is of more importance than might appear at first sight. It is obvious that an insufficient pull will never overcome shortening; but an excessive pull, though a much lesser evil, is still to be avoided, because (*a*) any traction in excess of requirements is an unnecessary strain upon ligaments, and (*b*) an extension glued to the skin will give way in the third or fourth week, sometimes lacerating the skin considerably and making further treatment difficult. Such an extension will only take a certain amount of pull at any time, and as the limb to which it is attached shrinks and the epidermal cells are shed, its adhesion becomes less. However, as the muscles weaken and consolidation commences, a less pull is required. If the extending force is limited to that actually necessary, and reduced as circumstances permit, the extension can be made to last the whole of the time required to get a satisfactory result. With a haphazard pull it cannot.

6. The pull exerted depends entirely upon correct application and continual adjustment. There is no automatic compensation, but any gliding of the extension, slipping of knots, elongation of bands, compression of pads, or wasting of the limb, means that the traction has been impaired, only to be restored when the apparatus is readjusted.

2. WEIGHT EXTENSION.

As opposed to the above method, the pull exerted by weight extension is exactly calculated, variable at will, and, being automatically adjusted, it remains of the required strength at all times and under all conditions.

It may be urged against weight extension that it is essentially a hospital method. True. But fractures are hospital cases, and under modern conditions can easily be brought within twenty-four to forty-eight hours to a hospital where treatment can be efficiently carried out. Counter-extension is amply good enough for the temporary fixation of a fracture during transport, but that is no reason why it should not be replaced by more scientific methods during the remainder of the treatment.

The chief drawbacks to the Thomas as a weight-extension splint, are the complete ring above and the closed end below. The complete ring is not being used for counter-pressure, and remains, like the pineal body and the appendix, a developmental indication of a different function in a former existence.

The fracture splint which I first saw at Blake's hospital in July, 1915, and whose use in cases of wounds of the knee-joint I described in 1916 and 1917,* seems to me to be the nearest approach to the ideal extension splint for fractures of the lower limb. It has the following advantages over a Thomas:—

1. *In manufacture.* It is made out of one piece of iron, and anybody can make it who has an elementary knowledge of the use of tools. I had mine made by a blacksmith at Bar-le-Duc at a trifling cost.

2. *In transport.* One dozen Blake splints can be put in the space occupied by four Thomas splints.

3. *In uniformity.* One size only is required, that for an average thigh. Not only does this simplify manufacture, supply, and distribution enormously, but a good fit is certain instead of being extremely rare. It is easy to make the upper end wider or narrower to fit any limb. Against this advantage must be set the fact that a different splint is required for the right or left limb.

4. *In ease of application.* The slings, padding, and foot-piece—if used—can all be fixed up beforehand, and the limb merely laid in the splint and fixed instantly. It is much easier to get the correct support for the limb in this way.

---

* *Guy's Hosp. Gaz.*, Oct. 21, 1916; *Lyon Chirurg.*, Jan. and Feb., 1917; *Brit. Med. Jour.*, Sept. 5, 1917.

5. *Fixation for travelling* is as good as in a Thomas, and is more rapidly effected.

6. *It satisfies all requirements in itself*, and can be used as: (*a*) A simple counter-extension splint, Thomas type; (*b*) Inverted, as a straight Hodgen; (*c*) As a trough splint with fixed foot-piece; (*d*) As extension splint, with sliding foot-piece, Sinclair type; (*e*) As screw-extension splint, Wallace-Maybury type; (*f*) As splint for suspension of foot by metatarsus.

7. *On reaching hospital*, it is ideally suited for slinging and weight-extension. Cords of the required length are kept ready, with hooks to fit on to the parts of the splint designed for this purpose, and each case is fixed up without any measuring or tying of knots.

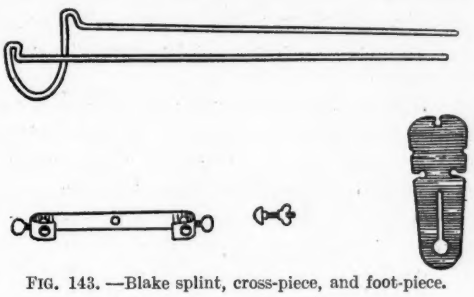


FIG. 143.—Blake splint, cross-piece, and foot-piece.

8. *During the course of treatment*, readjustment of slings or alterations in the foot-piece can be effected with the minimum of disturbance.

As used by us at Revigny, the Blake splint consists of the following parts (*Fig.* 143):—

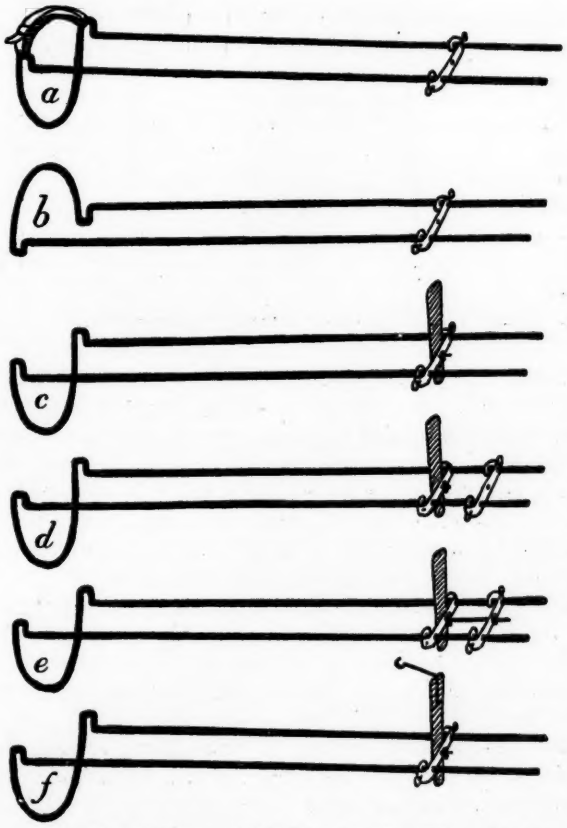


FIG. 144.—Various methods of using the splint: (*a*) As Thomas splint; (*b*) As straight Hodgen (inverted); (*c*) As trough splint with fixed foot-piece; (*d*) Ditto with sliding foot-piece; (*e*) Ditto with screw traction foot-piece; (*f*) As splint for suspension of metatarsus.

1. The splint itself. This is made of bar iron 9 mm. in diameter, and may be described as consisting of two parallel bars united at their upper end by a U-piece set at an angle. The inner limb is 105 cm. in length, the outer limb 10 cm. longer. Where the U joins each side bar, there is a small inverted bend 1·5 cm. wide. To these bends are attached webbing straps during transport, and the suspension cords during hospital treatment. These bends are turned outwards, so that the width between the upper ends of the side bars is 4 cm. greater than the width between the bends at their junction with the U. The U-piece is covered with flannel bandage covered with thin rubber, for which purpose a portion of the inner tube of a pedal bicycle tyre serves excellently. This padding is comfortable, clean, washable, and has no seams.

2. The cross-piece, which can be rigidly fixed to the side bars by its screws; or it can slide upon them, in which case a second fixed cross-piece is added to give the bars stability. Through the central hole passes a bolt with a wing-nut. To the lateral fixing-screws the lower suspension cords are attached.

3. The foot-piece, which is made of iron 2 mm. thick.

The various methods in which these three pieces of apparatus may be used in the treatment of fractures of the lower limb will be seen from *Fig.* 144.

Having reached the conclusion that weight extension combined with suspension is

not only theoretically the soundest, but is practically the best, method of treatment in war fractures, it remains to be seen what is the most satisfactory way in which these principles can be applied. We require an apparatus which will allow us to suspend any fracture, whether of the upper or lower limb, in any desired position, and at the same time to take a pull in the line of the fractured bone. Such an apparatus must first of all be efficient ; but granted that the above essentials are fulfilled, the simplest and cheapest apparatus is the best.

Where beds with rails at the head and foot are in use, it is very hard to improve on the simple frame originally introduced by Blake at the beginning of the war, and used continuously during the last three years at his own and many other French hospitals. A diagram (*Fig.* 145) will explain its construction more readily than a verbal description.

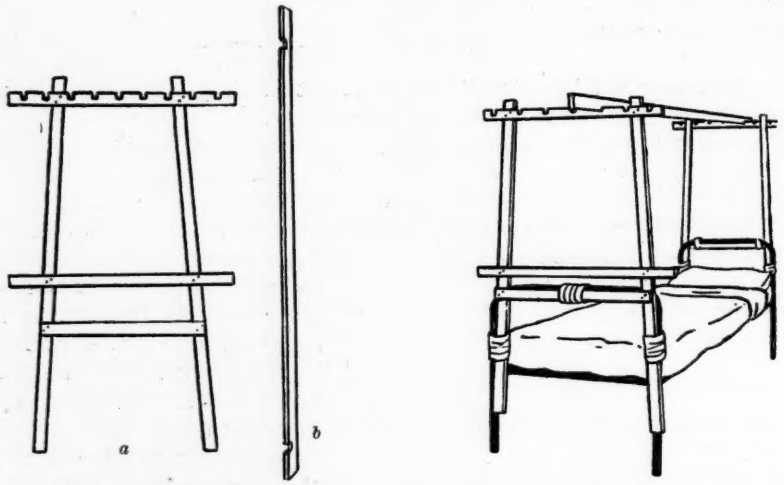


FIG. 145.—Blake's suspension-extension frame. (*a*) End member, (*b*) Overhead bar, (*c*) Frame erected.

It is light, strong, simple, and extremely cheap to make. The ones we had made at Revigny cost 8 francs each. It can be erected in a few minutes, and when erected becomes an integral part of the bed, to the weight of which it does not greatly add, so that in fine weather bed and frame can be carried together into the open air without disturbing the arrangement of the suspension. It can be used on both sides of the ward simultaneously, can be dismantled as soon as done with, and stored in a small space. But apart from this, it provides satisfactory attachments for the suspension and extension of any fracture of the upper or lower limb.*

In the case of the army beds which have no rail at the end, it would not be easy to attach such a frame to the bed itself. All requirements are, however, satisfied in such a case by three overhead bars of wood or stout gas-piping running the whole length of the ward. One is placed vertically above the shoulder, one at the level of the groin, and one at the level of the foot. Such bars may be fixed to the rafters supporting the roof (*Fig.* 147). Should any intermediate extension point be required (which is not often), it can be obtained by laying a 6-ft. wooden bar across two of the longitudinal beams, or by suspending a pulley between two beams with extension cord.

---

* Since writing the above I have seen in the *Manual of Splints and Appliances for the Medical Department of the U.S. Army*, compiled by a board of medical officers appointed to investigate the different forms of apparatus in use for the treatment of fractures, the following statement (p. 27): "After considerable investigation, the board has been convinced that the Blake pattern of quadrilateral frame erected over the bed has all the merits of the more cumbersome frames, and the following advantages: (1) Lightness of construction; (2) Cheapness of construction; (3) Increased rigidity in proportion to weight; (4) Economy of space; (5) Ease of adjustment for different positions.

If these overhead beams are used, it is necessary also to have some means of taking a horizontal pull at the foot of the bed. This is provided by a very simple frame (*Figs.* 146, 147), which is an amplification of one seen at No. 2 Red Cross Hospital, Calais, made portable and adjustable, and adapted to the army bed. It allows of extension at any desired angle of flexion or abduction, combined with any required tilt of the bed. It folds up flat, and can be stored easily and erected instantly.

The frame consists of a main member (A) and a supporting strut (B). B is united to A by strong hinges (1) at the sides, and furthermore a tongue (2) in the upper ends of the side bars of the strut B fits into corresponding slots in the side bars of A, locking the two firmly together when extended. A stout hook (3), fastened to A and fitting into a ring in B, makes the whole absolutely rigid when erected. In addition there is a movable cross-bar (4), which is attached to the holes in A by bolts and wing-nuts.

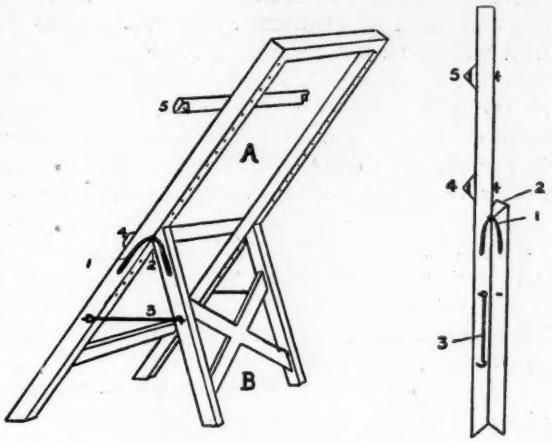


FIG. 146.—Frame—shown erected and folded– providing for a horizontal pull at the foot of a bed.

In use, the cross-bar (4) is put at the desired height, and the two iron side bars of the army bed are rested upon it. They are held laterally by the side bars of A, and are prevented from slipping back by the locking of their projecting knobs against the edge of the cross-bar (4). The extension pulley is attached to the top cross-bar of A. Should extension be desired with very little tilting of the bed, another cross-bar (5) is attached to A at the required height, to which bar the pulley is attached. With this combination of longitudinal beams and extension frame, all the requirements for the treatment of any fracture, whether of the upper or lower limb, are satisfied.

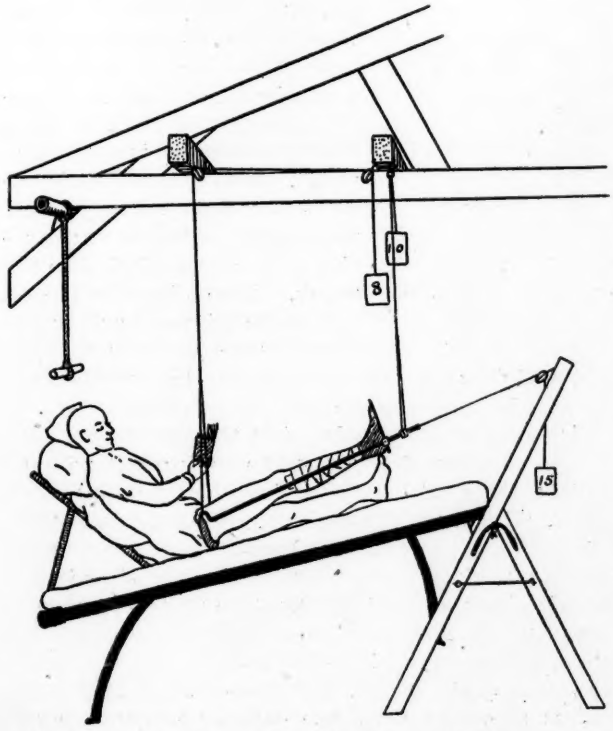


FIG. 147.—Scheme of extension for fractured femur.

Fractures of the Lower Limb.—Having discussed at some length the principles involved in the treatment of fractures, I do not suggest touching upon detail as regards the treatment of fractures of the lower limb. Suspension and weight traction can be applied in many ways, and the splint matters less than the way in which it is used. *Fig.* 147 illustrates the scheme of suspension in the case of a fracture of the femur, and shows the Calais frame and the longitudinal suspension bars in use. The splint is suspended by two cords only, attached by a running reef loop to two lengths of cord fixed

respectively to the upper and lower ends of the splint. By such an arrangement the splint is adjusted in the horizontal plane, and has then no further tendency to tilt. The Thomas splint is often suspended by four independent cords, to which are attached weights, which must be altered as needed in order to counteract the tilting which inevitably occurs.

The method illustrated has two obvious advantages over that of using the patient's own weight as the extending force.

1. The patient is comfortable. He can have as many pillows as he wishes, he can sit up to read or write, and he can move up or down the bed. He is less likely to develop chest complications. Yet he cannot increase or diminish the action of the extending force in the slightest degree, unless he brings the bottom of his splint down to the extending pulley on the frame. In a tilted bed this never occurs.

2. The method is as nearly automatic as anything can be in surgery. Lateral alinement looks after itself, and length looks after itself. The bone when united will not be too short, and, what is almost as important, it will not be too long, for the intramuscular fascial planes are strong structures, and it requires gross overpulling to lengthen them. The only thing that has to be combated is the tendency to backward sagging at the site of fracture.

Fractures of the Upper Limb. — Whatever difficulties there are in the application of splints to war fractures, these difficulties are much greater in the case of the humerus than of any other bone. Its upper third is enveloped by the muscles of the axillary folds and cannot be satisfactorily controlled by a splint. The shoulder girdle is impossible to fix. Not only is it extremely movable itself, but it is mounted upon that part of the trunk which is subjected to the greatest amount of movement. Here counter-extension is seen at its worst. The pull which is exerted depends entirely upon the amount of flexion or abduction of the arm relative to the trunk. Two diagrams (*Figs.* 148) make this point sufficiently clear. The humerus and the Thomas splint are drawn to scale. It will be seen that the distance between the two fixed points differs by as much as three or four inches in the extreme positions.

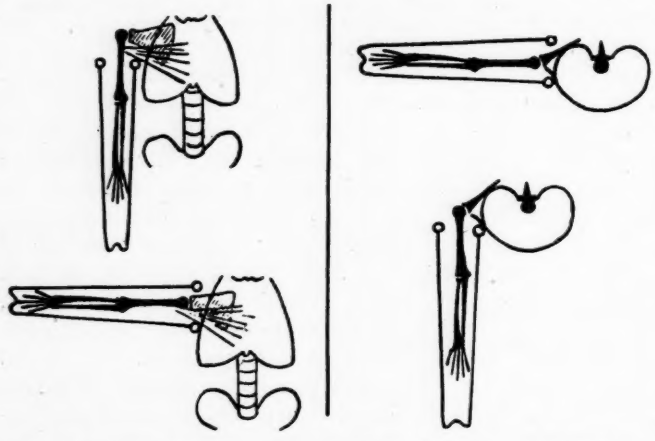


FIG. 148.—Diagrams showing effects of abduction and flexion of humerus in altering the distance between the fixed points in counter-extension.

The reason that counter-extension is so frequently employed in the treatment of the fractures of the humerus is that this method allows the patient to walk about with an ununited fracture. It appears to me that the case for ambulatory treatment is based upon an inverted view of cause and effect. It is argued that the improvement in a man's general health resulting from fresh air and exercise reacts favourably upon the progress of his wound. But the quickest way to get a man well is to remove the cause of his illness, and is therefore, in this case, to overcome sepsis and get the fracture united as soon as possible. The only certain means to attain this end is by providing adequate fixation. No splint properly controls a fracture of the humerus in both the walking and recumbent positions, and even the most ambulatory of patients spends eight hours out of the twenty-four in bed. The value of a method is shown, not by the date at which it allows the patient to walk about the hospital, but rather the date at which it allows him to walk out of the hospital cured. Judged by such a standard, the treatment of fractures of the humerus by simple weight-extension, as used by Blake, is one of the most strikingly satisfactory things in war surgery. The results obtained are excellent, and the effect of

continuously correct apposition of the ends of the bone, combined with slight movement at the seat of fracture, is that union is obtained remarkably early. So treated, it is common enough to see a fracture of the humerus united at the end of twenty-five days, in perfect position, with a full range of all movements at the elbow-joint.

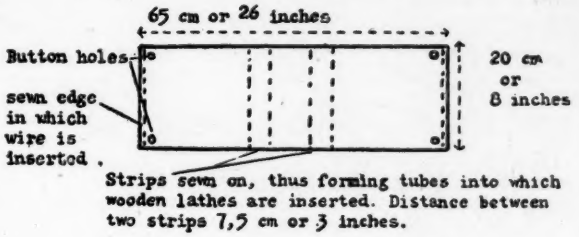

65 cm or 26 inches
Button holes
sewn edge in which wire is inserted.
20 cm or 8 inches
Strips sewn on, thus forming tubes into which wooden lathes are inserted. Distance between two strips 7,5 cm or 3 inches.

FIG. 149.—Diagram of canvas sling.

If a fracture of the humerus is treated by weight extension, a splint is no aid, but rather a hindrance. However, there are the natural splints, the muscles, lying in correct position, and only waiting to be put on the stretch to spring into instant action and force the fractured bone into correct alinement.

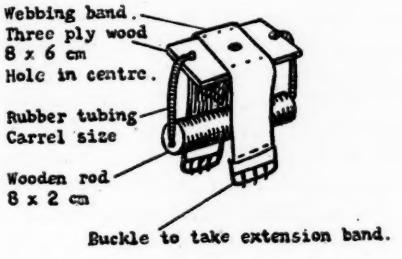


FIG. 150.—Diagram of finger exerciser.

Take, for example, the case of a fracture of the upper third of the humerus, where the deltoid is pulling the lower fragment outwards, and the pectoralis major, teres, and latissimus dorsi are pulling the upper fragment inwards. To try to push the fragments into position by local splinting, e.g., by Middledorf's triangle, is distinctly unsatisfactory. The command of the fragments is poor, and the distorting forces are not under control. The remedy is on the spot, and only needs to be used. The long head of the biceps lies between the tendons of the pectoralis major and teres; once it is put on the stretch, it pulls them back into line. The coracobrachialis and short head of the biceps splint the fracture internally, the deltoid is converted by traction from a distorting agent into an external splint, and posteriorly the outer head of the triceps bridges the gap and completes the series of natural supports.

In the treatment of fractures of the humerus, two additional pieces of apparatus are used: (1) A canvas sling, explained in the diagrams (*Figs.* 149, 151, 152); (2) A finger exerciser, useful but not essential. This, too, is self-explanatory (*Figs.* 150, 151, 152).

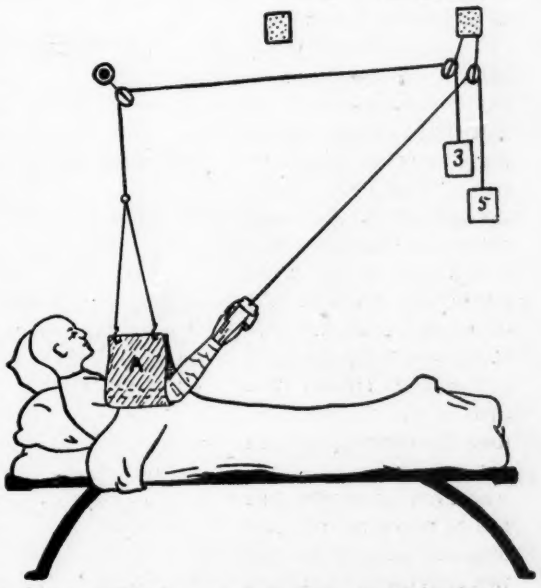


FIG. 151.—Scheme of extension of fracture of humerus, middle or upper third.

The method of slinging fractures of the humerus is more easily explained by diagrams than by verbal description. *Fig.* 151 shows the canvas sling, finger exerciser, and overhead bars. The weights shown are those usually required. As in fractures of the femur, it is best to overcorrect the tendency of the fracture to sag, and to reduce the weight later if it is found to be excessive.

In fractures just above the elbow-joint, a flexed position is desirable. When the limb is slung in this position, the forearm comes to rest in a position of three-quarter supination, and any trouble with fixation of the elbow in an extended position is avoided. In *Fig.* 152 a Calais frame is used to take a pulley carrying the extension cord from a figure-of-eight sling around the elbow.

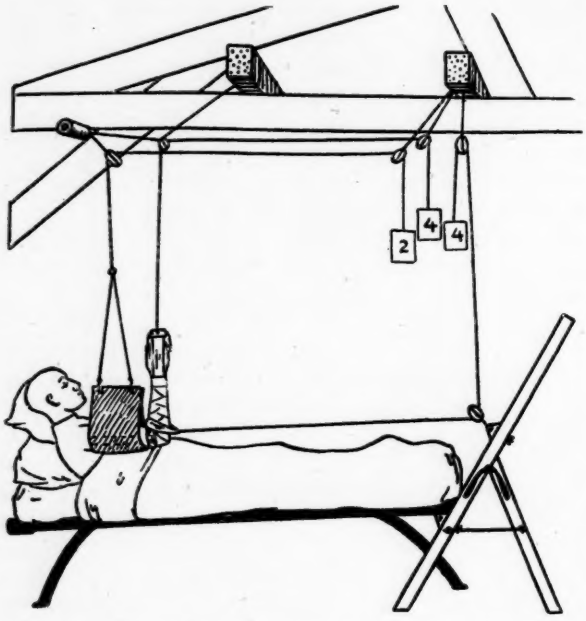


FIG. 152.—Scheme of extension of fracture of humerus, lower third.

Fractures of the Forearm and of the Wrist.—Just as in fractures of the tibia and ankle it is necessary to fix the knee, so in fractures of both bones of the forearm it is necessary to fix the elbow. Hence, even with weight extension, a splint is required. I use an adaptation of the Blake leg splint for this purpose (*Fig.* 153). It will be seen that it is very similar to the leg splint, except that it is lighter—of 7 mm. iron—is bent at an angle of 100 degrees, the U-piece is set at right angles to the side bars, and the side bars are strengthened 15 cm. beyond the bend by a cross-hoop welded on to them. The width between the bars is 12 cm., the length from the U-piece to the angle 19 cm., and from the angle to the lower end 65 cm. The cross-piece is identical with that for the leg splint, except for its size. The U-piece is padded with flannel covered with leather.

For the treatment of fractures of the forearm, an ordinary coat-hanger is attached to the under aspect of the side bars of the splint by two screw-rings, so that it can glide freely up and down. A cotton glove is glued to the hand, and a piece of cord tied to the tip of each of its fingers. Slings are then arranged along the splint, the arm is laid in position, and the upper arm held by a firm bandage. The forearm is now put in a position of full supination, and in this position the strings from the fingers are tied to the coat-hanger. The splint is now hung from the beams (*Fig.* 154), a weight of 4 lb. being usually sufficient, as the extension takes part of the weight of the limb. Finally,

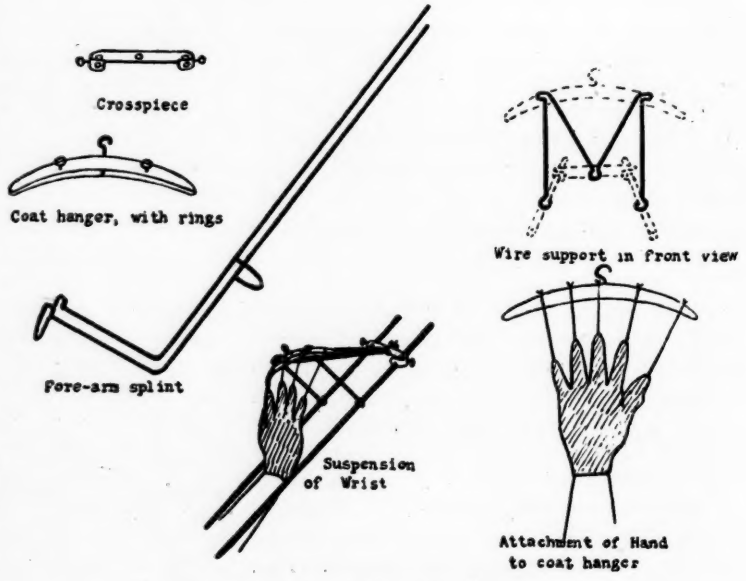


FIG. 153.—Apparatus for fractures of forearm.

a cord is attached to the hook of the coat-hanger, led through the central hole in the cross-piece, taken over a pulley on the lower roof beam, and a weight of 4 lb. is attached. Thus, continuous extension is secured in a position of full supination.

In the treatment of fractures of the wrist, where for some reason the patient must be treated in bed, the same coat-hanger is attached by the same screw-rings to a wire frame resting on the side bars of the splint, and clamped in position by the bolt in the cross-piece (*Fig.* 153). Suspension of the splint as a whole is all that is required to obtain dorsiflexion combined with moderate extension.

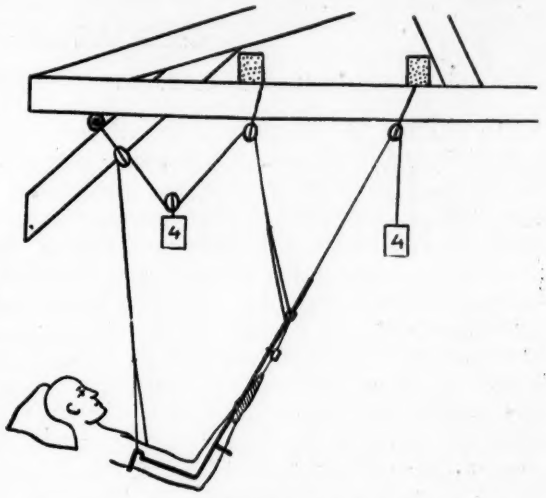


FIG. 154.—Scheme of extension of fracture of both bones of forearm.

CONCLUSIONS.

It may be said that it matters little what particular type of frames, or even of splints, is used; what matters is the way they are used. I have described the Blake splint which we used at Revigny, not in order to urge its adoption, but with a view to pointing out that our use of the Thomas splint is largely due to an unquestioning acceptance of an already existing apparatus. Weight traction is one of the oldest of methods, but it has nevertheless been largely lost sight of, and it is only by a series of steps, each following logically upon the last, that one has been led to the rediscovery that it is, after all, the best of methods. These steps have been :—

1. The use of one's favourite pre-war methods.

2. The adoption of the Thomas or some similar splint, used for the application of traction by means of counter-extension.

3. The discovery that results, though better, are still far from perfect. The pull is therefore increased, perhaps by screw traction, with resulting discomfort to the patient, development of pressure sores, and with not much better results.

4. To relieve this pressure on the skin, the bed is tilted and the splint tied to its foot, or weights are attached, primarily with the object of diminishing the pressure on the tuber ischii.

5. By stages of increased weight-pull it is discovered that when the ring is pulled right away from the tuber ischii, not only does no harm ensue, but almost perfect results are obtained.

6. Weight traction is substituted as a definite line of treatment.

7. One's ideas of splints are revised according to the new principles used. Much traditional apparatus is consequently discarded, and methods are progressively simplified in the light of experience.

THE DIAGNOSIS AND TREATMENT OF INJURIES TO THE CRUCIAL LIGAMENTS.

By Major S. ALWYN SMITH, D.S.O., Cardiff.

Up to the last ten years very little has been written concerning injuries to the crucial ligaments, and references in literature concerning the operative treatment for the condition have been scanty, and practically non-existent regarding the mechanism which produces the injury. References to the immediate suture of ruptured crucials have been made by Mayo Robson, Battle, Pagenstecher, Robert Jones, and Hogarth Pringle.

Pagenstecher, Honigschmied, and Dittel have written concerning the experimental rupture of these ligaments. In 1907, Hogarth Pringle described a case of rupture of the anterior crucial with avulsion of the tibial spine treated by operative means; this was the first instance described in which the rupture had involved the bony attachment of the ligament. About this time I was taking many radiograms of knee-joints for Sir Robert Jones during my association with him, and we were struck by the fact that intra-articular fractures were commoner than was anticipated, and that whereas some were connected with crucial ligament injuries, others showed no signs of any such ligamentous damage. The injury causing the damage to the knee-joint was in many cases almost identical; but whereas one patient sustained a sprained or torn anterior crucial, another would display a fractured external tubercle of the spine with no signs of crucial ligament injury.

Our investigations on the matter were collected and published in the first number of this Journal in 1913. The rôle of the crucials in sustaining the integrity of the knee-joint has not been fully recognized, although Corner, in an excellent paper on the surgery of the knee-joint published in 1914, pointed out the importance of the crucials in bearing strain in all movements of the knee. From the surgical standpoint the anterior crucial is more important than the posterior, as it is very much more liable to damage; in fact, one may say that the posterior crucial almost invariably escapes, except in those severe injuries that are connected with dislocation of the knee.

Since the war began, the question of anterior crucial injuries has been more forcibly brought to our notice on account of the great number of bad knee-sprains that we are seeing; this is doubtless due to the hardships of active service. 'Shell bursts' on the parapet cause men to be partially buried or forcibly thrown off their feet in various ways. 'Shell hole' cases, where men heavily equipped fall into muddy holes at night when going 'up' on ration parties, are obviously apt to cause more severe knee-joint injuries than ever come off the football field.

I wish to draw attention to the importance from the military standpoint of the sprained anterior crucial ligament in connection with injuries to the internal semilunar cartilage, and to emphasize that this is the main reason why operations for the removal of the internal semilunar cartilage have sometimes proved so unsatisfactory in the soldier. With regard to this point, I will speak more fully when describing the 'rocking' knee as the main symptom of the stretched anterior crucial ligament.

Anatomy.—The crucial ligaments extend from the intercondyloid notch of the femur to the non-articular area on the upper surface of the tibia. They are about the thickness of a slate pencil, and are invested by a prolongation of the synovial membrane, so that they are excluded from the synovial cavity although intracapsular. The anterior crucial is attached above to the inner side of the external femoral condyle at its posterior part. It passes downwards, forwards, and slightly inwards, and becomes fixed to the superior surface of the tibia in front of the internal tubercle of the spine, to the base of which a few of its posterior fibres are attached; it is also attached to the anterior horn of the external

semilunar cartilage (*Case* 3). The posterior crucial springs proximally from the anterior part of the outer surface of the inner femoral condyle, and passes downwards, backwards, and slightly outwards to the posterior rounded surface of the non-articular area of the superior surface of the tibia (posterior inter-condylic fossa), to which it is fixed.

The knee-joint is composed of three separate articulations, two femoro-tibial and one femoro-patellar. The two crucial ligaments are lateral ligaments of the femoro-tibial joints. The ligamenta alaria and ligamentum mucosum are the remains of the partition between the separate synovial cavities of this joint. Not infrequently one finds the ligamentum mucosum as a sheet extending backwards to become continuous with the layer of synovial membrane involving the crucial ligaments, thus isolating the two lateral synovial cavities (Paterson).

Mechanism.—It should be realized that the stability of the knee-joint depends upon the integrity of (1) The muscles acting on the joint, with their aponeurotic expansions ; (2) The capsule of the joint, and its reinforcements, the lateral and posterior ligaments ; (3) The semilunar cartilages ; and (4) The crucial ligaments.

Each and every one of these structures is dependent upon the other. The crucial ligaments stand a large amount of strain in any abnormal movements of the knee-joint. The anterior crucial is tight when the joint is extended, becomes slack in semiflexion, and tense when the joint is fully flexed. The posterior crucial is tight in full flexion, becomes slack in semiflexion, but with the joint in full extension the ligament again tends to become tense. It is thus seen that in full extension of the joint the anterior crucial prevents antero-posterior mobility of the joint, and the posterior one fulfils the same rôle in full flexion of the joint. The amount of tension, however, is merely relative, as can be easily demonstrated by forcibly pulling and pushing the head of the tibia on an anæsthetized person with the knee in semiflexion. It is found that the amount of sliding of the tibia on the femur is very slight.

Extension of the joint is limited by : (1) The hamstring muscles ; (2) The ligament of Winslow ; (3) The lateral ligaments ; (4) The anterior crucial ; (5) The posterior crucial. The most important are the ligament of Winslow and the anterior crucial. Rotation is prevented in the extended position by all the ligaments before mentioned. In semiflexion a certain amount of internal rotation is allowed, on account of the relaxation of the anterior crucial and the internal lateral ligaments. Paterson is of opinion that internal rotation is mainly limited by the crossing of the crucial ligaments, the anterior pressing on the tightening posterior.

In the semiflexed position external rotation is comparatively free. It is limited by the superficial fibres of the internal lateral ligament to a certain extent, but mainly by the deep attachment of this ligament to the internal semilunar cartilage (the coronary ligaments). The anterior crucial and the external lateral ligaments have no limiting action at all. Paterson thinks that the posterior crucial ligament limits this rotation as it becomes tightened. This I have not been able to verify clinically (*Case* 4).

Adduction of the knee is limited by the external lateral ligament and the posterior crucial, aided by the wedge-like semilunar cartilages. Abduction of the knee in the fully extended position is limited by the superficial fibres of the internal lateral ligament. When the knee is semiflexed more than 20 degrees, these fibres pass out of action, and the main source of stability is now (1) The deep internal lateral ligament ; (2) The anterior crucial ligament. Lateral sliding of the knee is prevented by the crucial ligaments, and by the semilunar cartilages on account of their wedge-like shape, and also by reason of their attachments to the lateral ligaments. All fibres of the lateral ligaments also assist in preventing sliding movements.

The commonest form of knee sprain combines abduction of the knee with external rotation of the tibia, the knee being in the semiflexed position. The deep fibres of the internal lateral ligament attached to the internal semilunar cartilage become torn, and the cartilage either fractures or is displaced. Should the abduction of the knee continue further, the entire strain is borne by the anterior crucial ligament, which becomes in its turn stretched or torn, or the internal tubercle of the tibial spine becomes avulsed.

It is obvious that the severity of the lesion to the anterior crucial ligament is dependent upon the strain to which the knee is exposed. When one examines a knee-joint which has sustained an injury that betokens a damaged internal semilunar cartilage, the examination is not complete without verifying the integrity of the anterior crucial. Rotation outwards is always more obvious after removal of the internal semilunar cartilage, as is also abduction in the semiflexed position (*Case* 4).

Several cases have been seen where the cartilage has been removed and the symptoms of locking have been relieved, but the weak 'rocking' knee has remained. In each case the patient was of opinion that the laxity of the knee was due to faulty operation, until the true nature of the injury was explained to him. It is thus expedient to safeguard oneself by a thorough examination to verify the structures that are damaged. Where there has been an avulsion of the tibial spine, the symptoms of laxity are often masked ; on account of the new bone formation there is inability to fully extend the knee, and forward sliding of the tibia is prevented. During operation for this condition, with the muscles acting on the joint relaxed under the anæsthetic, the anteroposterior mobility of the tibia manifests itself markedly.

Clinical Manifestations.—The following types of lesion may occur :—

A. Due to Direct Trauma.—(1) Rupture or stretching of both crucials, due to grave injuries to the joint such as dislocations of the knee ; rarely the crucials may be destroyed by gunshot wounds passing laterally through the joint. (2) With bony involvement—avulsion of the tibial spine—anterior crucial only. (3) Combined with torn or displaced internal semilunar cartilage—anterior crucial only. (4) Rupture or stretching of one crucial ligament without other damage—uncommon in anterior, rare in posterior crucial.

B. Due to Mechanical Causes (*Indirect Trauma*).—(5) Genu recurvatum—producing laxity in both crucials—anterior more than posterior.

Crucial laxity may also occur :—

C. Due to Disuse.—(6) Inflammations in or around the knee-joint—the lateral ligaments are more apt to suffer, the crucials generally escape (*Case* 6). (7) Disease or trauma of hip requiring long immobilization—the same results are found as in (6).

D. Due to Disease.—(8) Charcot's disease—generalized disintegration of all ligamentous structures connected with the joint.

In classifying lesions of the crucial ligaments, it is important to remember that tearings are always due to severe trauma, but that stretchings can occur as the result of continued strain due to mechanical causes. Disuse of the knee-joint apparently affects the lateral ligaments more than the crucials, and continued extension, as in the treatment of fractures of the femur, has the same result—the crucials appearing little the worse. Charcot's disease affects all ligaments of the knee to a similar extent, and an extreme flail-like joint results.

From the clinical aspect, the anterior crucial is of greater importance than the posterior, being more liable to injury. The combined rupture of the external lateral ligament and lax posterior crucial is a rare condition, and I only remember having seen one or two cases.

A stretched anterior crucial is almost invariably associated with a torn internal semilunar cartilage, except where the injury has been a forcible hyperextension of the joint that has stretched the ligament of Winslow and the anterior crucial at the same time ; this type of case is rare, but if the case is of long standing, genu recurvatum will be present and the tibia can be brought forward on the femur in the hyperextended position. Conversely, the anterior crucial may be gradually stretched in malunited fractures of both bones of the leg, set with an anterior concavity. Here the body weight is thrown behind the centre of the knee-joint, and the anterior crucial and the ligament of Winslow have strain thrown upon them at every step taken (*Case* 5).

In avulsion of the tibial spine, where the cause is usually a fall in the flexed and internally rotated position of the tibia, the internal semilunar escapes as a general rule, although it is not an uncommon history to find that a displaced cartilage has been diagnosed and even operated upon, the true condition having remained undiagnosed. It is essential that all cases that display inability to extend the joint fully should be radio-

graphed, although the bone block of a tibial spine case should readily be diagnosed from the 'elastic' block of a displaced internal cartilage.

Rupture of the posterior crucial alone is very rare, and I have never seen a case.

Rupture of both crucials can occur in forward dislocation of the tibia with hyper-extension of the knee, and also where the tibia is dislocated backwards and upwards. Lateral dislocation has produced the dual lesion, and in addition there may be paralysis of one or both of the popliteal nerves. In all these cases of severe injury there is a flail-like knee.

When the tibia can be brought forwards on the femur in full extension, the anterior crucial is definitely ruptured. When the posterior crucial is ruptured, the tibia may be displaced backwards into the ham with the knee in full flexion.

In old-standing cases the anterior crucial may be found to be, not fully ruptured, but stretched and attenuated; to all intents and purposes the condition is quite as serious as a complete rupture, for secondary immobilization even for a prolonged period does not appear to strengthen it.

The stretched or torn anterior crucial combined with a tearing of the internal semilunar cartilage appears to be a commoner injury than is generally supposed. The diagnosis is made in old-standing knee-joint injuries by the combined symptoms: (*a*) Locking of the joint; (*b*) Rocking or slipping of the joint, combined with a feeling of insecurity. As will be seen from the reports of *Cases* 1, 7, 8, and 9, periodic lockings took place. There was marked abduction at the knee in semiflexion, and rotation of the tibia externally, and to a lesser extent internally, was increased; the tibia could in each case be brought forward on the femur in the extended position. The removal of the cartilage cures the 'locking,' but will, if anything, increase the rocking and slipping of the tibia on the femur. *Case* 4 is a good example of this point. Here the strain was purely a lateral one involving the inner side of the knee. The distal attachment of the deep internal lateral ligament did not give way, but brought a piece of the articular edge of the internal tuberosity of the tibia with it, producing a rare example of a sprain-fracture of the deep internal lateral ligament. The internal semilunar cartilage was obviously displaced *in toto*; this is well seen in the photograph of the specimen (*Fig.* 158). All strain was now borne by the anterior crucial, which became stretched. After the loose bone and the attached semilunar were removed, the general laxity of the joint increased, as will be seen in *Figs.* 159, 160.

TREATMENT.

Generally speaking, the immediate treatment of injuries to crucial ligaments should be conservative rather than operative. Recent injuries to the joint that show abnormal mobility should be *x*-rayed as a routine. This will eliminate avulsion of the tibial spine. Where there is rupture of both crucials due to lateral or posterior dislocation of the knee, the limb should be immobilized with the knee flexed to 20 degrees for at least three months, but faradism to the quadriceps and general massage with movements of the patella should be practised daily. Good results have been reported by many observers from treatment by prolonged fixation of the joint. Should there be, as sometimes happens, a paralysis of one or both of the popliteal nerves due to stretching, postural and electrical treatment for the nerve injury must also be undertaken. Where there is a recent avulsion of the tibial spine, despite the advice of Hogarth Pringle, I think it is wise to try the effect of immobilization of the knee in the fully extended position for twelve weeks, combined with the massage and faradism as mentioned above, rather than to treat the case by primary operation and fixation of the detached ligament and its bony insertion. In cases of old standing, however, operative measures are indicated.

Prolonged immobilization can be carried out equally well by means of splint or plaster of Paris. The former is, I think, preferable, in that massage can be carried out more fully in the early stages when the patient is confined to bed. After three or four weeks the long skeleton splint can be substituted by a Thomas calliper, which will enable the patient to get about with comfort.

Secondary wasting of the quadriceps, especially the vastus internus, will not be so pronounced and will not require such prolonged after-treatment to restore this musculature to its previous tone if massage and faradism are instituted at once.

The after-treatment of anterior crucial injuries can generally be undertaken by means of appliances. In the ordinary course of events a Marsh cage splint will pervent the abnormal mobility that is present when one or other of the crucial ligaments has been ruptured or stretched. This, of course, means that the appliance will require to be worn for an indefinite period. In conjunction with the cage splint, a Japanese crêpe bandage wound around the knee will often be beneficial as an additional security. In anterior crucial cases the boot should be raised both sole and heel on the inner side, to throw the strain against the external lateral ligament and prevent any tendency to abduction at the knee or rotation outwards of the tibia on the femur. The 'rocking' knee that has been operated upon for a loose internal semilunar cartilage, and whose symptoms are now those of a lax anterior crucial ligament, may be dealt with in this way if no operation is desired. This, however, is the type of crucial ligament injury that it is advisable to help by operative means, as the thought of always wearing a mechanical support is repugnant to many young men, and the inability to take part in games and athletics is a prime factor in the desire for radical treatment. It was in cases of this description that in 1916 I attempted plication in one case and the insertion of a silk ligament in another. Both these operations failed somewhat ignominiously. However, I intended to substitute an intra-articular tendon fixation should another case present itself. My idea was to utilize the biceps by threading it from femur to tibia in the course of the anterior crucial ligament, or to use the semitendinosus by dividing it in the thigh and then threading the distal end from tibia to femur, fixing the upper free end at the upper and outer side of the femur. However, before these ideas could be tried out, Hey Groves brought out his fascial ligament operation, which is undoubtedly a great advance on anything that has been done before. It is early yet to speak of after-results; but so far as my own four cases are concerned, the results of the operation, somewhat modified from that described by Hey Groves, justify continuance of the procedure in certain selected cases.

Operative Treatment of Anterior Crucial Injuries.—The following operations have been done at varying times, apart from those of immediate suture of the ligaments as mentioned before: (1) Plication; (2) Reefing (Corner); (3) Wire loops (Corner); (4) Silk ligament substitution; (5) Fascial substitution (Hey Groves).

1. My experience in plication of a stretched anterior crucial ligament is limited to one case (*Case* 1), and the result did not justify a repetition of the operation. As will be seen from the report, the ligament was found at the operation to be thinned and markedly lengthened, so much so that with a blunt hook one was enabled to bring the ligament forwards to a considerable extent with the knee in flexion. The ligament was split longitudinally, and each lateral half was pulled outwards, thus making the ligament diamond-shaped. This diamond was stitched with chromic catgut into the shape of a Maltese cross, in the same manner as one frequently shortens a tendon.

The result at the time appeared satisfactory, and the knee became appreciably more stable. After prolonged immobilization the clinical result was very unsatisfactory, the weakness of the leg being as apparent as it was before the operation was performed. The lack of control was so marked that, despite the use of a cage splint, the patient asked that an arthrodesis of the knee should be done. This operation was performed four months after the one referred to for the shortening of the ligament, and it was interesting to remark the changes that had taken place in this structure. The ligament appeared shorter than at the previous operation, but its consistency was soft and jelly-like, akin to myxomatous degeneration; on putting a blunt hook behind the ligament and pulling on it the ligament readily tore in half.

2. Edred Corner devised a reefing operation in which he took up the slack of the ligament by means of a non-absorbable suture which was passed round the ligament and fixed through holes drilled in the condyle of the femur. This operation seems to give little chance of permanent improvement, as the atrophic ligament is too weak to maintain the stability of the joint

3. Corner also described an operation for the replacement of an anterior crucial ligament by means of two loops of wire, one of which is fixed through the external condyle of the femur, and the other through the internal tuberosity of the tibia. The utility of this operation appears to be very limited, as one feels that the result would be, to say the least, very transitory, on account of rarefying osteitis around the wire.

4. Another case of anterior crucial rupture came under my care, and the use of the cage splint was found to be insufficient. The question of suture of the ligament or arthrodesis of the knee was discussed with the patient, who preferred the chances of the former operation. As will be seen by the case history, the ligament was found to be torn from its tibial attachment, and its condition was such that the whole of it came away with gentle traction by forceps. The degenerated ligament was very soft and friable.

The idea of a silk ligament presented itself, and the principles underlying Lange's work on tendons seemed to hold good. The external femoral condyle was drilled, as was the tibial tuberosity, in the manner devised by Corner. Eight ply of silk were pulled through the channels thus made, and the new ligament was fastened at its upper and outer aspect by a wire keeper which was hammered into the bone. The flexed tibia was pushed backwards on the femur as far as possible, and the silk was knotted and stitched to the periosteum on the antero-internal surface of the tibia, and, to make doubly certain, was also stitched to the infrapatellar tendon. After the wound was stitched up, the stability of the knee-joint appeared to be normal.

The progress of the case was uneventful for fourteen days, but the joint was immobilized for eight weeks. A certain amount of synovitis persisted, but when passive movements were begun about the tenth week the synovitis was more noticeable. About the eleventh week a small sinus appeared at the lower end of the wound, and the temperature became elevated. The knee-joint was freely opened for the purpose of producing drainage and subsequent ankylosis. The whole joint was extremely congested, the inflammation being not only in the synovial membrane (including the fat pads), but in addition the cartilage was decidedly pink and non-articular portions of the joint were tremendously injected. All the tissues to which the silk had been tied were friable, and the same condition was noted as in the previous case—to wit, the myxoma-like appearance of the tissues. The arthritis was evidently due to the silk acting as a foreign body.

After the lack of success of the silk ligament scheme, it was resolved that should another case present itself which could not be satisfactorily treated by conservative measures, we should use the tendon of the biceps, in whole or in part, or the semitendinosus, to make a new anterior crucial ligament.

5. No case, however, appeared until Hey Groves brought out his operation of substituting a strip of fascia lata for the crucial ligament. This operation was described in the *Lancet*, 1917, Nov. 3, p. 674, and appears to be a great advance on anything that has been done before. From the clinical standpoint, I think the operation is incomplete, in that it does not attempt to strengthen in any way the internal lateral ligament, so that the new fascial strip has to bear the entire strain of abduction of the knee as well as of anterior sliding and internal rotation of the tibia on the femur. It seemed advisable to attempt to reconstruct the deep fibres of the internal lateral ligament in some way, and the autogenous transplant of fascia lata was the first idea that presented itself.

I reconstructed an external lateral ligament of the ankle-joint in an extremely bad old-standing case of sprained ankle that had required the use of an appliance. The result was very satisfactory. I then tried the same experiment in a case of extreme lateral mobility of the knee due to a bullet wound of the knee-joint, of sixteen months' standing (*Case* 6). In addition, I divided the sartorius four inches above its insertion and brought the free distal end beneath the periosteum in the region of the adductor tubercle. The result of this case was also very gratifying. The first of a series of four anterior crucial reconstructions had, in addition, a sartorius fixation, but no fascial transplant. It then became apparent that the operation could be much simplified, and that the same strip of fascia lata could be made to take the place not only of the anterior crucial ligament,

but also of the internal lateral ligament. The operation has been performed on three cases, and is carried out as follows :—

FIG. 155.—Diagram to show location and size of fascial strip.

The field of operation includes the region of the knee and the full length of the thigh. A tourniquet is applied at as high a level as possible on the thigh, the knee is flexed to 60 degrees, and a J-shaped incision is made as for an excision of the knee, the inner limb being about six inches in length, and the transverse portion of the wound passing across the tubercle of the tibia ; the outer limb of the incision must be at least twelve inches in length. The incision passes through the skin and fascia only. The flap is now dissected upwards over the patella ; all the skin edges are covered in and clipped with wound towels. The patella is divided vertically, and the two halves are separated. The anterior crucial ligament, covered by synovial membrane, is examined. The upper level of the suprapatellar pouch is now noted, as it is advisable that the fascial strip should pass through the femur at a slightly higher level to avoid any unnecessary intra-articular disturbances. A long drill with a diameter of $\frac{1}{4}$ in. is now bored through the internal surface of the external condyle at the site of the upper attachment of the anterior crucial ligament. The drill-hole must pass upwards and outwards, and should emerge through the shaft of the femur externally at the upper level of the suprapatellar pouch. The internal tuberosity of the tibia is now drilled in the same way, beginning slightly anterior to the insertion of the sartorius, passing upwards, backwards, and slightly outwards, and emerging on the superior articular surface of the tibia just anterior to the internal tubercle of the tibial spine. A strip of fascia lata $1\frac{1}{2}$ in. wide is now cut. This strip is attached at its bottom end, and in the ordinary course of events should be between $9\frac{1}{2}$ and 10 in. in length (*Fig.* 155).

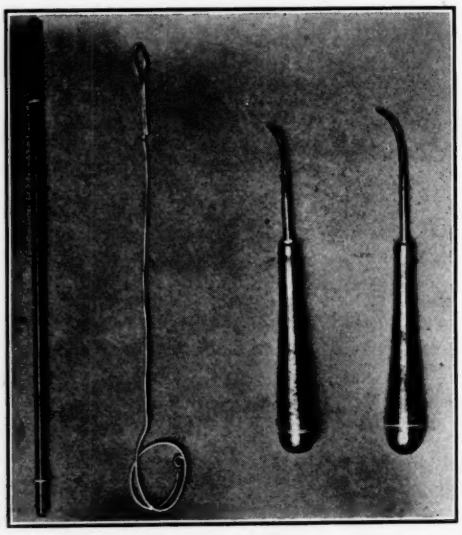


FIG. 156.—Drill, flexible probe, and shoemakers' awls, used in the operation.

The two lateral incisions in the fascia are joined at their upper end, and the new fascial ligament is stripped downwards from the subjacent muscle. A long flexible probe with an eye large enough to take the fascial strip is now pushed, eye first, through the tibial drill-hole into the knee, and upwards through the femoral drill-hole until it emerges on the outer side of the femur. The free end of the

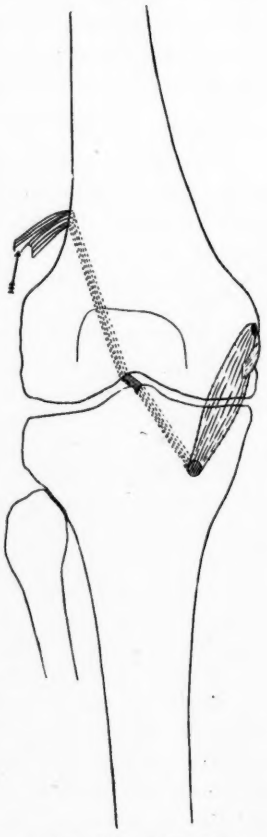


FIG. 157.—Diagram to illustrate course of new anterior crucial ligament.

fascial ligament is now threaded, and the probe is withdrawn, bringing the fascial ligament with it. As much tension as thought fit can now be applied to the new ligament, and the tibia is forced backwards on the femur as far as possible.

A channel from before backwards in the inner condyle of the femur about the adductor tubercle is now drilled. This cannot be easily done with a straight drill or bradawl, but is very simply made with the largest size shoemaker's awl, which makes a curved channel (*Fig.* 156). This can be enlarged to the requisite size. The free end of the fascial strip is then threaded through this channel from before backwards and pulled as tight as possible, both in its anterior crucial portion and also in the internal lateral part of its course, and is stitched to the periosteum around the tibial orifice, and also to itself after it has passed through the adductor drill-hole. Strong chromic catgut is the suture material of choice. The fascial ligament appears to curl on itself as it passes through the bone, and makes a ligament about the thickness of a slate pencil (*Fig.* 157). As Hey Groves points out, the tension of the attached portion of the strip is from below upwards, and consequently strengthens the external lateral ligament. The two halves of the patella are brought together, the leg is carried to a position of 20 degrees of flexion at the knee-joint, the tourniquet is removed, the hæmorrhage stopped, and the patella stitched together by three or four chromic-catgut sutures through the aponeurosis. A small cigarette drain is placed between the two halves of the infrapatellar fat pad, but not extending into the joint cavity. The skin edges are approximated by Michel's clips.

The leg is put up on a Thomas skeleton splint with a foot-piece, in a position of 20 degrees of knee flexion. The drain is removed in forty-eight hours. A certain amount of oozing continues until the third day, so a second dressing should be undertaken on the fourth day. At the end of a fortnight a cast is applied, still with the knee slightly bent. At the end of four weeks massage and faradism to the quadriceps begin, and gentle active movement is permitted ; a support, however, should be worn for another fortnight.

Hey Groves has suggested the use of the semitendinosus tendon for the replacement of the posterior crucial ligament. It is carried out in the same way as his operation for anterior crucial substitution, the course of the posterior crucial ligament being followed by drill-holes. This operation is of greater difficulty than the one described above. On account of the rarity of posterior crucial injuries, this operation will have a limited field.

The surgery of the crucial ligaments is an interesting problem ; it should, however, be reserved for selected cases, though the operation described appears to produce no more trauma in the knee-joint than the usual transpatellar operation.

SHORT NOTES OF NINE CASES.

Case 1.—**Stretched anterior crucial ligament treated by plication.**

Pte. G. History of having slipped and fallen while in trenches, March, 1915. The left knee was twisted. Not much pain till next morning, when knee was much swollen. Reported sick two days later, but kept on duty. Knee became worse, and locked on several occasions; these were accompanied by swelling. Was forced to fall out on route march on account of locking, pain, and swelling about April, 1915, and was then sent down the line. Ever since first strain in March, patient noticed a 'looseness' about the knee. Operation for removal of internal semilunar cartilage in a general hospital in England, May 17. No more locking of knee followed operation ; otherwise there was no improvement, and great insecurity was felt in the joint.

On admission, Nov. 17.—Complained of leg always rotating externally when putting any weight on heel. Left knee shows marked extraneous mobility and hyperextension. Rotation of tibia outwards and inwards on femur increased. Old scar of previous operation on medial side of knee-joint. *X* ray normal.

Treated by altered boot, flannel bandage, and calliper splint, with massage and faradism to quadriceps for four months; no improvement. Cage splint was tried, but found quite inefficient, as the foot rotated externally at every step.

Operation, April 6, 1916.—Split-patellar arthrotomy through U incision. Anterior crucial ligament exposed and found to be very much thinned and stretched. The ligament was split vertically and plicated, the lateral halves being pulled outwards and the sides of the diamond thus formed stitched together in the shape of a cross. This procedure stabilized the knee-joint in antero-posterior mobility considerably. Convalescence uneventful.

After two months' immobilization joint was as unstable as ever. Patient desired an arthrodesis of the knee, which was done. At this operation, it was found that the anterior crucial ligament was very soft, friable, and swollen, appearing to the naked eye almost like a myxomatous degeneration. A point of surgical interest was that the articular surface of the patella showed no signs whatsoever of having been divided at the previous operation.

Case 2.—**Ruptured anterior crucial ligament treated by insertion of a silk ligament.**

Cpl. L. Sprained left knee while in training, December, 1914. After going to France had much knee trouble, the knee locking while marching, and in addition there was unnatural movement in knee with feeling of insecurity; as time went on this became more marked.

On admission, June 13, 1916.—Diagnosis of torn anterior crucial ligament made. It was decided to attempt to suture the ligament.

Operation, July 6.—Split-patellar arthrotomy through U-shaped incision. Anterior crucial ligament found to be torn from its tibial attachment. Free end of ligament was picked up with forceps, and entire ligament, which was obviously degenerated, came away quite readily. Tibial end of ligament found to be only ¼ in. long, and this too was soft and friable.

It was resolved to make an intra-articular silk ligament. A drill-hole was made from the non-articular outer surface of external condyle, parallel to joint and opening at the intercondyloid notch in region of the femoral attachment of anterior crucial ligament. A double wire was thrust through the hole from without, and the loop made to present in intercondyloid region. Eight ply of No. 3 silk now brought through this channel by means of the wire loop. Upper and outer end of silk knotted to a loop of phospho-bronze wire which acted as an anchor, and this was hammered into the bone so as not to protrude into joint. It was found impossible to stitch the silk to tibial end of the ligament, so another hole was drilled in an upward and backward direction from tubercle of tibia, the drill emerging at the tibial attachment of the anterior crucial ligament. By means of a wire loop the silk strands were brought out through this hole to front of tibia. The silk was pulled as tight as possible, well knotted, and also stitched through infrapatellar tendon. Wound was closed in usual way, and joint found to be quite stable, especially in antero-posterior movements of tibia on the femur.

Convalescence uneventful except for synovitis, which persisted, and when movements began after seven weeks it became more marked. Ligament operation unsatisfactory, as a sinus appeared after nine weeks which necessitated opening up the knee-joint and producing ankylosis.

Case 3.—**Avulsion of tibial spine of six months' standing. Removal of bone obstruction. Anterior crucial implantation.**

Sec. Lieut. F. The patient had a history of having sustained injury to left knee in May, 1917, by falling into a shell hole with the leg flexed underneath him. On being helped out knee was absolutely fixed, and he could neither bend nor straighten the leg. Pain was excruciating, and marked swelling immediately followed. Was sent down the line, remaining at a C.C.S. two days without any treatment; was then sent to a base hospital, where a box splint was applied; he remained there two days and was then sent to a hospital in this country. Was operated on for removal of internal semilunar cartilage in June. A posterior splint was used for one day only following the operation. Passive movements were begun in a fortnight. There was very little movement at this time. Massage was instituted and continued for six weeks, and very slight improvement in movement resulted. Was now sent to a Command Depôt, where whirlpool baths and massage improved matters somewhat. After four months 40 degrees of movement was present.

On admission, November.—Patient could flex knee to 40 degrees. Full extension was limited by 25 degrees, the obstruction appearing osseous rather than fibrous. No anterior crucial laxity could be elicited. *X* ray showed definite fracture of inner tubercle of spine of tibia, with new bone formation.

Operation, Nov. 27.—Joint exposed through split-patellar route. All excess bone on anterior part of tibial spine chiselled away. Anterior crucial ligament found to be fully separated from tibia, a few fragments of bone remaining attached to it. Ligament was held in position by its synovial covering, but a few of its most external fibres were found attached to anterior horn of external semilunar cartilage. Ligament embedded in the raw area of bone that remained after excess callus was removed. Knee found to extend fully, and after wound was closed in the usual manner the whole lower extremity was immobilized. Leg was kept immobilized in the extended position for twelve weeks to make sure of efficient union of ligament to the tibia. Knee now lacks 15 degrees of full extension, and there is limitation in flexion, but this is improving. There is no laxity in the joint.

Case 4.—**Stretched anterior crucial ligament, with fracture of portion of internal tuberosity of tibia, involving deep internal lateral ligament and semilunar cartilage.**

Sec. Lieut. S. Buried by a high-explosive shell, April 6, 1917. Was thrown on to his right side, and the weight of the earth fell on outer side of left knee with the leg bent. On being dug out there was much swelling of knee, which was very painful. During the next day or two the entire leg swelled and became discoloured owing to generalized bruising. Was sent down the

line. At Blackpool, about a month later, treatment by massage and ionization was begun, and continued for about three months, but synovitis persisted, though he could get about with knee rigid by aid of a stick.

On admission, Sept. 15.—*X* ray showed a loose piece of bone, evidently detached from articular margin of inner tuberosity of tibia. Constant locking of the joint took place on walking on uneven ground or taking a false step. Synovitis followed each derangement, and some fluid was always present in the joint. On examination, there was preternatural abduction at the knee, marked increase in rotation outwards, and slight increase in rotation inwards of tibia on the femur. Synovitis was present. Knee was kept at rest to reduce effusion preparatory to operation for removal of the loose piece of bone.

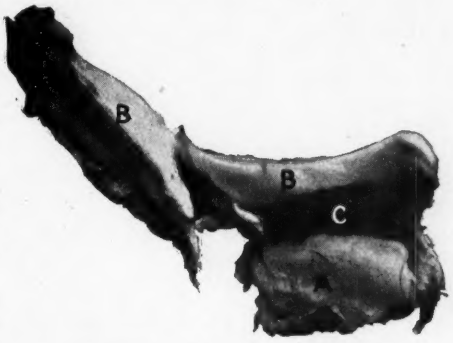
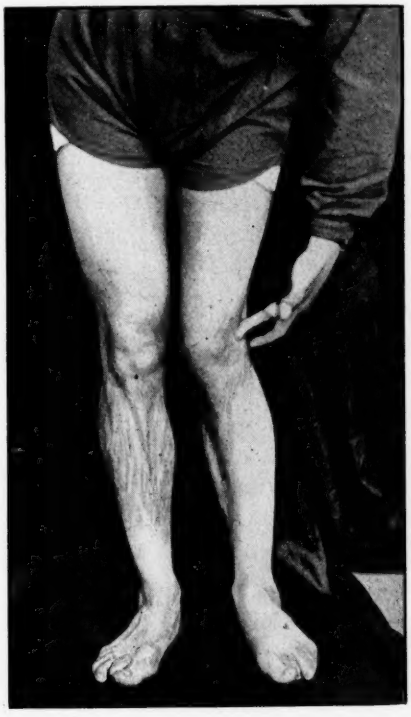


FIG. 158.—*Case* 4. Specimen removed from knee-joint. **A**, Superior articular surface of tibia. **B**, Internal semilunar cartilage. **C**, Suspensory ligament.

Operation.—A curvilinear incision was made over inner aspect of joint—longer than is usually employed for removal of the internal cartilage. On opening the joint capsule, fractured surface of the loose bone presented itself. With gentle traction on the fragment it came away easily, with little dissection. The whole of the internal cartilage was found to move with it. A complete circumferential tear of the cartilage had occurred, and the meniscus was attached to the joint at its anterior and posterior horns only. These attachments were divided, and the mass with attached cartilage was removed. The specimen (*Fig.* 158) shows that the bony mass consists of a thick flake of bone, mainly superior articular surface of tibia; but the suspensory ligament attaching it to the semilunar cartilage is intact. It is unfortunate that the semilunar had to be divided transversely to remove the anterior horn. As expected, locking of the joint was cured, but 'rocking' was increased (*Figs.* 159, 160).



FIGS. 159, 160.—*Case* 4. After operation, showing laxity of the joint.

The use of a cage splint combined with an altered shoe, after the tone of the quadriceps was improved by massage and faradism, brought about improvement, and patient was able to get about with comfort. The cage splint will require to be used for an indefinite length of time.

Case 5.—**Genu recurvatum due to malunited fracture of both bones of the leg, causing secondary stretching of the anterior crucial ligament owing to faulty mechanism in walking.**

Cpl. M. Injury received December, 1916. A 'dud' trench-mortar shell struck his left leg on outer side. There was fracture of tibia at junction of middle and lower third, and of fibula at two points 5 inches apart; no acute pain or swelling in knee at the time or since. Four unsuccessful attempts to reduce fracture, and finally tibia was plated at end of January, 1917. A fortnight later leg was put in plaster, and casts were continuously worn until May, when there were still no signs of union. Passive congestion and massage were now instituted, and continued until August. Plates were removed, and leg was reset and put in plaster again in September, the tibia being concave anteriorly.

On admission, December, 1917.—It was found that union had taken place in bad position. Tibia markedly concave anteriorly. There was a certain amount of valgoid deformity of the lower fragment, which was internally rotated as well. The tendo Achillis and tibialis posticus were contracted, and the peronei atrophic and weak, the foot being in a position of equino-cavo-varus. A boot and appliance were ordered, to throw foot into valgus position, the peronei were massaged and faradized, and patient was instructed to walk. A month later there was marked laxity of the anterior crucial. The tibia could be brought forwards on the femur, and rotation inwards was markedly increased.

Operation, April 12, 1918.—An osteotomy just above old site of fracture was performed, together with lengthening of shortened tendo Achillis and tibialis posticus.

Union in good position has occurred. Patient at present walking with a cage splint.

Case 6.—**Gunshot wound of suprapatellar pouch followed by marked lateral ligament laxity treated by autogenous transplant of fascia lata to reconstruct the internal lateral ligament.**

Lieut. P. Wounded September, 1916. Bullet entered anterior aspect of knee-joint in suprapatellar region and lodged in joint. Wound dressed seven hours after. Sepsis followed, and temperature reached 104°. Knee-joint aspirated three days after infliction of wound. Four days later, operation to remove the bullet, which was not found. Two days later another attempt was made which was successful—tube drainage for forty-eight hours followed. Dressed daily for two weeks and was then transferred to Malta. Here the joint was aspirated under general anæsthesia. Extension by means of a Balkan splint applied. After five weeks, transferred to England wearing posterior splint. Voyage lasted three weeks, during which time he wore a back splint and had daily massage. Between December, 1916, and May, 1917, was treated in two hospitals in this country by ionization, counter-irritation, and massage. Transferred to Command Depôt in May, where massage was continued, but in addition whirlpool baths and forcible flexion were instituted. Improvement in movement noticed.

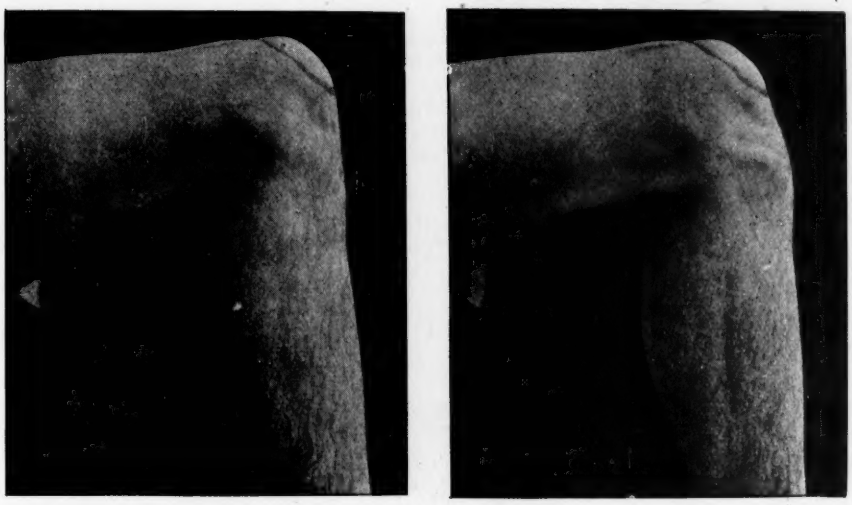
On admission, November, 1917.—All wounds healed—scars on both lateral and medial aspects of knee, which is swollen and weak. Extension full, flexion to 90 degrees, marked lateral mobility of joint, no crucial involvement. Massage and movements continued for two months, with altered shoe to relieve strain on internal lateral ligament. No improvement in lateral mobility.

Operation, Jan. 29, 1918.—Horseshoe incision on inner aspect of knee-joint. Internal lateral ligament exposed. Sartorius divided at upper margin of wound, and upper end of lower portion stitched to periosteum of internal condyle, being tightened as much as possible in the process. A strip of fascia lata 3 in. by 1½ in. taken from outer side of thigh was sutured to inner portion of joint superficially to the sartorius tendon, and stitched above and below to periosteum of femur and tibia respectively. Wound closed without drainage. Leg immobilized for four weeks.

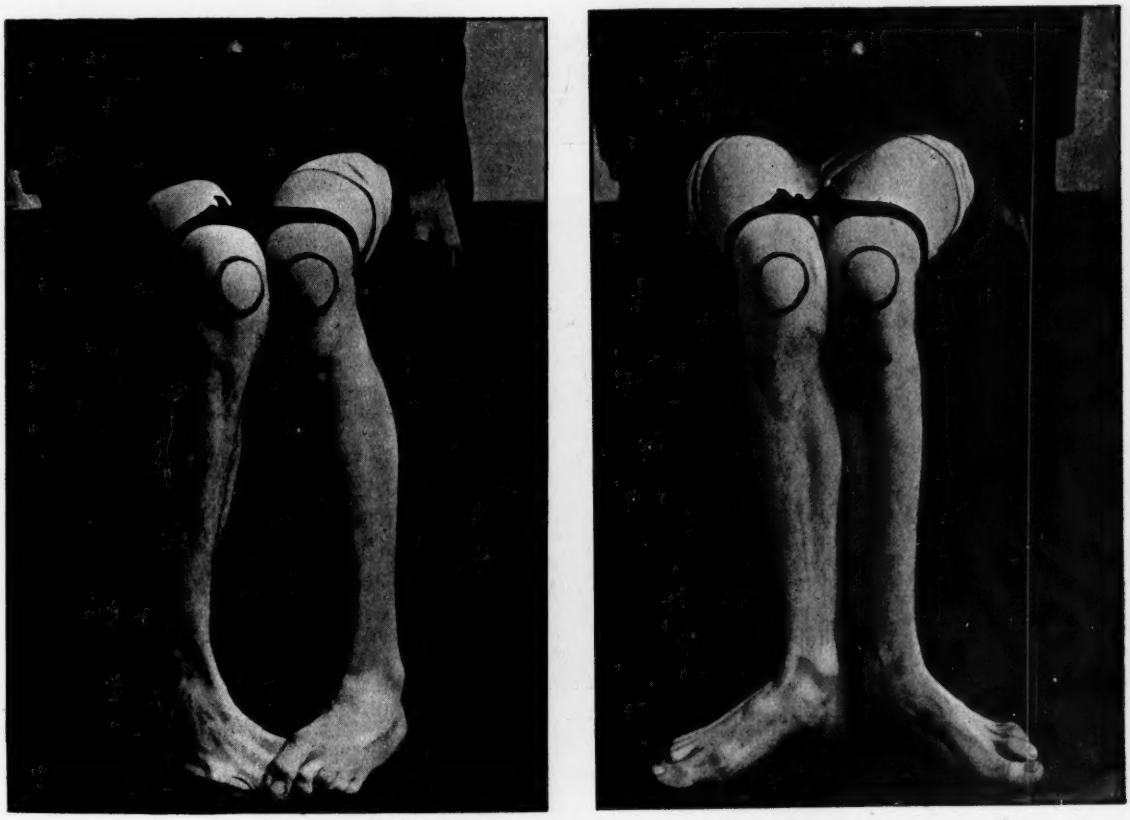
After eight weeks the lateral mobility was markedly improved—the new ligament appearing quite firm. Knee was still painful if a mis-step was taken, but patient could walk well, and derived great benefit from the operation. Sent to duty at home.

Case 7.—**Anterior crucial laxity with tearing of the internal semilunar cartilage. Treated by fascial ligament and sartorius fixation.**

Lieut. C. Injured right knee by falling into a trench, February, 1917. Was at once removed to a dressing station, where it was found he could neither flex nor extend the leg, nor allow it to be manipulated on account of the extreme pain. Marked swelling in knee from onset of injury. Leg was fully extended and fixed in a back splint, and he was sent down the line and arrived in England a few days later. Remained in a London hospital three weeks, and was then sent to a convalescent home. Here he was given massage, which produced pain, and swelling in joint. After a month's treatment he was boarded and marked for G.S. in one month. While home on leave, knee began slipping, as he was walking more than he had hitherto been able. A definite locking followed a mis-step, and the leg 'let him down.' Following this locking, all the old symptoms returned. He reported at the nearest military hospital, where he was admitted and put to bed, with counter-irritation to reduce the synovitis. After six weeks was transferred to special hospital where the internal semilunar cartilage was removed. Two months' after-treatment, during which time no further lockings occurred, but knee was more unstable



FIGS. 161, 162.—*Case* 7. Showing anteroposterior 'rocking' movement of tibia on femur.



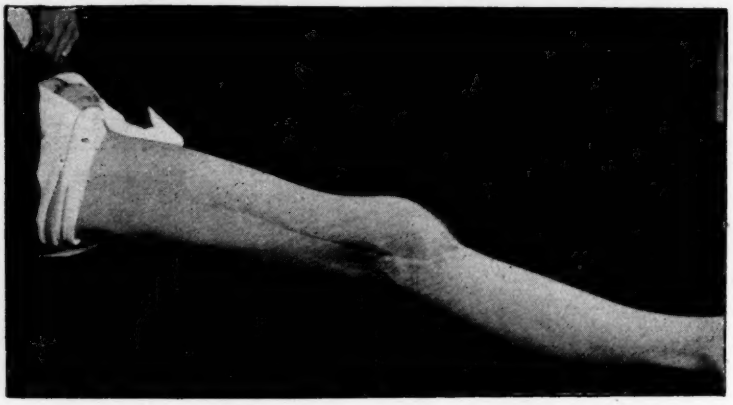
FIGS. 163, 164.—*Case* 7. Showing increase in inward and outward rotation of tibia.

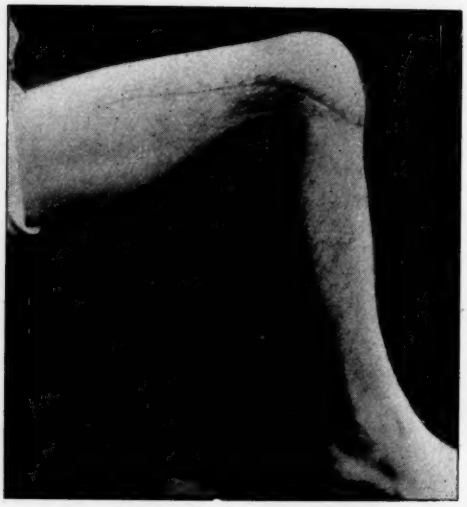
than before the operation, and appeared to continue slipping, although this was not painful as before.

On admission July, 1917.—Knee-joint was very mobile, and at will the tibia could be pushed forwards on the femur, causing a definite slip or 'rocking' movement (*Figs.* 161, 162). Rotation inwards increased, rotation outwards markedly increased (*Figs.* 163, 164). Treatment by internal crooking of sole and heel and a cage splint instituted, combined with massage and faradism of quadriceps. No improvement followed, and joint continued to display the most alarming mobility as regards lateral and anterior movement combined with rotation in both directions of tibia on femur. Patient was very dissatisfied with his condition, and readily agreed to operative interference.

Operation, February, 1918.—Usual U incision and split-patellar route. Sartorius was divided above level of inner condyle and the upper end of lower portion was stitched to periosteum about the adductor tubercle. Anterior crucial ligament was thinned and atrophic. Fascial ligament constructed.

After-result: Lateral mobility not much improved. Antero-posterior mobility greatly improved, and since the tenacity of quadriceps is increasing by massage and exercises the improvement becomes more obvious. The sartorius fixation is the weak point of this operation (*Figs.* 165, 166).





FIGS. 165, 166.—*Case* 7. After operation for construction of new fascial ligament.

Case 8.—**Torn anterior crucial and loose internal semilunar cartilage. Treated by fascial ligament. Standardized operation.**

Pensioner L. History of having been buried in the trenches by high-explosive shell, December, 1914. A shell burst on the parapet, buried him with his right knee doubled under him—he thinks

in full flexion with rotation inwards of tibia on femur. Knee-joint was locked, very swollen and painful, almost at once. Taken to advanced dressing station, where leg was manipulated and extended, which caused much pain. Arrived in England three days after, and was in hospital until March, 1915. No treatment given for knee condition, but other wounds (shell wounds of left hand) were healed and have since caused no disability. Sent to Command Depôt in March, and became Instructor until February, 1916, when he was discharged from army on account of numerous 'lockings' of knee-joint and general instability of the knee.

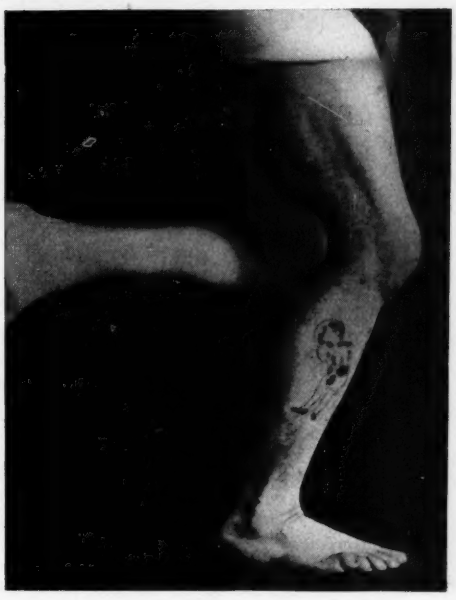


FIG. 167.—*Case* 8. After operation for construction of new crucial ligament. Showing stability and weight-bearing capacity of the joint with a partly flexed knee.

On admission, March 8, 1918, as a pensioner.—General complaint is of weakness of right knee that has prevented him from doing any work, though he has tried several times. Knee has locked innumerable times—this can always be reduced by the patient. In addition, knee-joint appears 'wobbly,' 'the bones slipping and rubbing on one another' as the patient puts it. On walking, there is dull aching pain in the internal and posterior aspects of joint. Can flex and extend to normal. There is slight lateral mobility when joint is fully extended, but very marked when joint is flexed to 20 degrees. Tibia can be brought forwards on the femur appreciably, especially with knee in semiflexion.

Operation, March 19.—Usual anterior crucial and internal lateral fascial substitution. Internal semilunar cartilage was found circumferentially torn, and was removed. Anterior crucial ligament apparently non-existent, being markedly atrophied.

Cast removed April 22. Knee decidedly firmer in lateral mobility, and antero-posterior mobility has disappeared. There was 30 degrees of voluntary flexion at once, and patient walked across ward without appreciable limp and without pain (*Fig.* 167).

This pensioner now has a full range of movement. There is no preternatural mobility of the joint. Walks well without limp.

Case 9.—**Stretched anterior crucial with cartilage trouble. Treated by fascial ligament. Standardized operation.**

Cpl. P. On Dec. 10, 1917, at a training camp, while running, he slipped on the ground and fell with his leg doubled up and rotated outwards. About ten minutes later he straightened his leg out, but felt something slip in the joint. Was able to limp back to hut. Joint became swollen immediately, and locked again as soon as he returned to the hut, and again that night while in bed. At this time some one had to straighten his leg, as he could not do it himself. After each locking there was an increase in swelling. After twelve days' treatment by rest and lotions in the lines, was transferred to a military hospital. During this interval he had about fifteen lockings. At hospital, treatment by a back splint was continued until Jan. 15, 1918. Splint was now removed and he was allowed to get about. On Jan. 22 the leg locked again. He was ordered to bed, dressings were applied (no splint), and he remained there until end of February, when he was allowed up wearing elastic bandage. Had one locking between this and March 15, when he was transferred.

On admission, March 15.—Elastic bandage on knee. Pain and tenderness around joint—unable to flex leg beyond a right-angle without considerable pain. Much lateral mobility and external rotation of leg. Tibia can be moved forwards on femur, suggestive of a stretched anterior crucial.

Operation, March 22.—Usual crucial and internal lateral ligament operation, with removal of internal semilunar cartilage, which was found torn circumferentially. Immobilization for five weeks, after which movements were begun. Is now walking well.

AFFECTIONS OF THE LARGE JOINTS DUE TO GUNSHOT WOUNDS: THEIR LATE RESULTS AND TREATMENT.

By S. W. DAW, Leeds.

Interference with the functions of joints by gunshot wounds may be manifested in several ways. Among the most important are: (1) *Limitation or absence of range of movement;* (2) *Undue mobility;* (3) *Alterations of the axis of movement.* The disabilities connected with reduction of power to move an otherwise healthy joint belong chiefly to the realm of muscle and nerve surgery, and are outside the scope of this article.

1. **Limitation or Absence of Normal Range of Movement.**—The factors to be considered are, first, the immediate effects of the wound; and secondly, the subsequent effects from suppuration and adhesions.

a. The missile may enter or pass through the joint, smashing or injuring the articular surfaces, or may without immediate damage set up a process of suppuration leading to a secondary destruction of the articular cartilage.

b. There may be a partial or complete fracture near the joint, leading to a mechanical bony block to movement from imperfect reduction of the fracture, displacement of a fragment of bone, excessive callus, or traumatic myositis ossificans.

c. Soft parts only, such as synovial membrane, capsule, ligaments, tendons, muscle, or skin, may be wounded, and, from immediate destruction, suppuration, and final healing by granulation, lead to adhesions or contractures having a pronounced effect in limiting the normal joint movements. The actual site of contracture or adhesion may be over the joint, or at some distance from it, as in the case of adhesions of soft parts to the shaft of a bone.

d. Reflex muscle spasm as a guard against painful movement of an unhealed or imperfectly cicatrized deep wound may of itself cause limitation of movement.

Diagnosis.—An exact diagnosis should always be aimed at, though it may not always be possible to hit the target. A routine treatment by massage and passive movements is to be deprecated, both in the interests of the patient and of science. Much time may be wasted and valuable chances lost if this empirical method is adopted. It is necessary, first, to learn as far as possible what are the difficulties to be met, and next, to decide what is the best way in which they may be overcome.

Diagnosis is made by inspection, palpation, and *x* rays. Inspection may at once reveal an obvious source of trouble. For example, a scar in the flexure of a joint, as at the front of the elbow, may cause no interference with flexion, but when extension is attempted there will be a drag on the scar which will prevent full movement in that direction. In other cases the nature of a deformity or the position of a scar may point directly to the cause of limitation.

Gentle attempts at passive movement will yield valuable information. The joint may be without movement; but, whereas in the presence of bony ankylosis the rigidity will be absolute and unyielding, in the case of fibrous ankylosis there will be a slight springy recoil accompanied by pain in all attempted passive movements, which will serve to distinguish it from the former condition.

Where movements are merely limited, there may be a sudden and complete stop to movements in one direction, while other movements are more or less free, pointing to the presence of a bony block at one point standing in the way of further movement, or an adhesion on the opposite aspect of the joint acting as a drag or brake to movement. The position of the wound will then help to a decision, as well as the nature of the resistance, whether absolute or elastic.

Where the limitation is not confined to one movement, it is often difficult to make an exact diagnosis. If, however, any one or more movements of the joint are *free*, it is probable that there is no serious intra-articular lesion, as such movements would be impossible in the presence of a definite arthritis. An example from civil practice will illustrate this point. In a case of suspected 'hip disease,' the presence of a full range of rotation will be a point against the diagnosis of tuberculous arthritis, and will indicate some cause outside the joint for any limitation of flexion or extension which may be present. Limitation of every movement is to be considered as a sign of arthritis or of a serious lesion of the joint.

The stiffness from muscular spasm is of a different character from that already described. The resistance is more gradual, and is accompanied by visible muscular contractions and a complaint of pain, without a point of definite stoppage being reached.

X-ray examination is desirable in all cases, and essential in those which are of a doubtful nature. Bony ankylosis is usually unmistakable; the joint cavity is obliterated, and bone in continuity is seen bridging the joint region. Cases of arthritis with complete or partial fibrous ankylosis may show a general cloudiness of outline, a definite irregularity at one or more points in the shadows of the ends of the bones, or in some cases merely a narrowing of the space between the ends of the bones, due to thinning or destruction of the cartilages of the type of plastic arthritis. It is most important and necessary in difficult cases to have a control skiagram of the corresponding healthy joint of the opposite side. Bony block nearly always occurs on the flexor aspect of joints, and is seen as a well-defined shadow near the joint, while the latter appears normal. It is important to remember that in a profile view of a joint an abnormal bony mass may appear to block movement, whereas it is really at one side and may thus cause no obstruction. If careful examination of the skiagram in comparison with that of the healthy opposite joint reveals no change, it must be considered for purposes of treatment that the lesion is outside the joint proper, or is at least of such a kind as is likely to yield to treatment.

2. **Undue Mobility.**—This condition is seen chiefly in the upper limb, notably in the shoulder- and elbow-joints. As a sequel of gunshot wounds, it is usually the result of excision of the joint in question at an early date after the infliction of the wound. A smashing wound of the joint has occurred, and the surgeon removes as far as possible all chance of a spreading infection by making a clean sweep of the damaged tissues. In observing these cases at a later stage, it is impossible to offer criticism of the method employed, as what seems to be a poor result may possibly represent a life or limb saved. It should, however, be clearly understood that these early and extensive excisions lead to extremely bad functional results. There is a wide gap separating the bones which should form the joint, the fulcrum action of the joint is gone, and very little active movement is possible. There is in fact a pronounced form of flail joint. In the case of the shoulder the arm hangs by the side, and only small degrees of flexion, extension, and abduction are possible to the patient. In the similar case of the elbow, the forearm and hand dangle from the elbow, usually without power of active movement. With wide excision of the wrist, the result is even worse: the hand is displaced forward, with deformity of the 'Madelung' type, the carpus being drawn upwards in front of the forearm bones; the alinement of the flexor and extensor tendons of the hand is wrong; and the fingers are held nearly straight and are entirely useless. Moreover, in none of these instances is there any tendency to natural recovery. There is very little bracing action of the muscles and tendons crossing the excised joint, and the weight of the useless portion of the limb below the excision tends to stretch the soft parts still further. In the case of joints which are stiff, time and natural processes may help to effect improvement; but these flail joints will usually remain useless unless treated on the lines presently to be indicated.

3. **Alterations of the Axis of Movement.**—These are of the greater importance in the lower limb, where the function of weight-bearing has to be considered, and especially in the knee and ankle, which act as hinge joints. Mal-union of fractures of the femur

may interfere with the normal transverse axis of the knee-joint in the direction either of genu varum or valgum. The former is usually of an innocuous degree; but the latter, by increasing the normal angle between the long axes of the femur and tibia, not only imposes extra strain on the internal lateral ligament of the knee, but also puts extra strain on the mediotarsal joint, and induces a condition of flat-foot. Malunion of the tibia, when it throws the weight to the inner side, alters the normal axis of the ankle-joint, and so puts strain on the mediotarsal joint, also producing flat-foot.

Manipulation of Joints.—This term is here applied to a procedure by the surgeon to improve the condition of a joint by moving it through a part or all of its range under general anæsthesia.

Before it is undertaken, two considerations must be weighed: (1) *What harm may result;* (2) *What good may result.*

1. The possible objections to manipulation are: (*a*) Lighting up of suppuration; (*b*) Possibility of fracture; (*c*) Liability to increase the disability rather than to reduce it.

As regards *suppuration*, it should be borne in mind that practically every case of a stiff joint from a gunshot wound has been the subject of suppuration. It is therefore generally essential that all wounds should be soundly healed for several months before manipulation is undertaken. The risk of recrudescence is not then absent, but is lessened enough to make the procedure justifiable. In rare instances where a joint threatens to become ankylosed in a bad position, it may be deemed necessary even in the presence of unhealed wounds to move the joint cautiously and gently into a better position, but this should never be done where there is any strong resistance to be overcome—that is to say, when adhesions have already formed. For general purposes, the standard of three months' freedom from suppuration must be adhered to.

The danger of *fracture* is small if proper precautions are used. These are: (i) The application of steady continuous pressure in the required direction, as opposed to jerky muscular efforts; (ii) The light application of metal gutter splints along the whole length of the bones above and below the joint to be moved. It should be the aim of the operator to make a restrained use of an excessive force—as, for example, by bearing the weight of his trunk transmitted through his arms along the whole line of the bone below the stiff joint—rather than to attempt to obtain the required movement by putting forth all the strength of his arm muscles. If the force is applied as described, it is easy to stop at any moment, as it is well under control. The portion of the limb above the joint should be laid flat on a sandbag on the operating table, to obtain steadiness and to let the stress be borne by the whole length of the bone. The use of the gutter splints is a valuable additional safeguard, and is especially needed when there has been a previous fracture of one of the bones involved.

The danger of *increase of the stiffness* by manipulation will depend on the judgement in selecting the case and on the method used. It is now generally admitted that no amount of to-and-fro movement will make rough surfaces smooth, or convert damaged joint surfaces into sound ones. Quite the reverse is the case. The breaking down of adhesions between the cartilages will leave raw, bleeding surfaces. The trauma of the violent movements will increase hæmorrhagic or inflammatory effusion within the joint. The resultant pain will call for prolonged rest, during which time the adhesion of the cartilages will become stronger than ever. If pain and effusion are ignored, and frequent passive movements under anæsthesia are persisted in, the inflammation will be kept up, and the period of rest, which is merely put off, will again lead to resumption of the stiffness. The idea of mobilizing a joint which has been the seat of arthritis in this way must therefore be abandoned as almost certain to do harm rather than good.

2. To turn to the other aspect of the case, the possibilities of doing good by manipulation must be considered. As has been stated, the prospects in the case of arthritis are limited, but at the same time they are very well defined.

Firstly, manipulation may here be used to correct a deformity and to put a joint into a more useful position. For instance, an arthritic knee may have a small range of movement round about 140 degrees. In this position it is comparatively useless.

The knee may be fully straightened by manipulation. If the joint is then quite stiff, the limb is much more useful than before. It may be found, however, that in the course of use a small range of movement from full extension will develop, and give a good walking leg as a result.

Secondly, even in the case of arthritis, judicious manipulation may lead to an increased range of movement. The destruction of cartilage may be limited to one part of the joint, which will usually be fixed in a faulty position from the point of view of function. If the joint is then moved into a position as remote as possible from its former one, each damaged portion will now lie in contact with healthy cartilage. The joint is kept at rest in its new position until all reaction has subsided. The fresh adhesions which have formed will be of a much less serious character than those originally present, and future gradual change of position may now result in quite a useful range of movement. Even in more general arthritis of a joint, manipulation may prove useful if one is content with a small degree of movement, followed by a period of rest until pain and swelling are absent, when the process may be repeated. Much may sometimes be gained by cautious movement of this kind, where drastic measures would do more harm than good. It will be seen, therefore, that in cases of this sort an effort must be made to reduce trauma to a minimum. This is done by abstaining from going too far at once, and by avoidance of all to-and-fro movements, with rest for the joint while any inflammation is present. In the case of the elbow- or knee-joint, the Turner splint (*Fig.* 168) may take the place of such manipulation, or be used to supplement it. This splint consists of portions to be attached to the limb above and below the joint, with an intermediate screw adjustment over the joint. It is fixed to the limb above and below by incorporation in independent sets of plaster-of-Paris bandages over a layer of cotton-wool. The screw may be adjusted to flex or extend the joint, a small change being made daily.

FIG. 168.—The Turner splint.

In connection with either method, voluntary active movements may be encouraged when they become possible; but what has already been said will make it clear that passive movements are worse than useless in an attempt to increase the range of the joint.

When we turn to the consideration of stiffness of an extra-articular origin, a more hopeful prospect of manipulative treatment comes into view. The stiffness in such cases may be due to adhesions or contractions of synovial membrane, capsule, ligaments, tendons, or muscles, to contractions of extensive skin scars, or to bony blocks of the kind already referred to. The last two conditions require special treatment, to be referred to later. The others lend themselves to manipulation for the breaking down of adhesions, with the hope of obtaining a good range of movement. The dangers of fresh suppuration or of fracture must be avoided by the precautions already referred to.

The force is applied as described above; but unless resistance is very great, the joint should be carried through its full range of movements at once. Here, again, inflammatory reaction must be reduced as far as possible, and each movement should therefore be carried out once only. Nothing is gained by repeating the movements.

The after-treatment varies somewhat according to the severity of the case. If the resistance appears to be light by previous examination, gas anæsthesia may be used. As the patient regains consciousness, he is told to put the joint through its movements.

This will give him confidence and assist in future treatment. Judicious passive movements are of great value in such cases. On the following day the joint is put once only through its full range. On the next day, again, its condition is noted. If the pain is less, active and passive movements are proceeded with. If the pain is greater and movement less, it is a sign that longer rest is needed. Further passive movements must be deferred until inflammation has subsided, as shown by the reduction of pain. Gentle stroking massage will be valuable in getting rid of inflammatory swelling.

In the case of more serious adhesions, such as are usually present in gunshot injuries, ether anæsthesia is advisable, so as to give more complete muscular relaxation and to allow more time for the manipulations. The inflammatory reaction is greater, and early passive movements are thereby often contra-indicated. The joint is to be kept at rest, usually in a position remote from that present before the joint was moved, and further movement is started cautiously. The case of the elbow-joint may be taken as an example. Stiffness is usual at about 120 degrees. The joint is put through its full range, and is then slung at rest in as full flexion as possible having regard to the circulation, say about 40 degrees. On the following day passive movement is gently tried. If it is painful, the joint is kept at rest in flexion for about a week. The sling is then relaxed to allow a small range of active movement from full flexion. If this range of active movement is maintained, after a day or two the sling is relaxed a little more, and so on. If, however, active movement becomes less, it is a sign of the need of further rest, and the joint is returned to rest in full flexion for another week, when the process of gradual letting down is again started. In somewhat less severe cases it may be possible to change the position from full flexion to full extension daily with gradually decreasing pain.

The indications for movement in after-treatment may be summarized thus :—

Passive movements are of little use, and may be very harmful in the presence of intra-articular lesions. When the lesion is outside the joint, they are of little use in increasing the range of a joint, but are most valuable in keeping up a range of movement already gained by manipulation. They should never do more than put the joint once through its full range, as nothing is gained by repeating the movements, and inflammatory reaction is thereby increased.

Active movements performed by the patient are nearly always of value, and can rarely do harm in the class of cases under discussion. They should not be used during a stage of obvious inflammation following manipulation, but as soon as inflammation has subsided and pain is gone, or much reduced, they can do nothing but good. At a later stage, the use of a partially stiff joint in a gymnasium, curative workshop, or civil employment, will often lead in the end to a better result than can be quickly obtained by any of the surgical means at our disposal.

Scars Limiting Movement of Joints.—These occur chiefly in the flexures of joints, especially the front of the elbow and the back of the knee. It may be possible to straighten the limb with or without general anæsthesia, and to keep it straight on a splint. If the latter is removed in a short time, the contraction will reappear, and no active power of straightening will be retained. To prevent this recurrence it is necessary to keep the scar on the stretch for a long time, perhaps three to six months. Contraction of scar tissue does not go on indefinitely, and if the stretching is maintained, surrounding skin will be drawn upon in course of time and adapt itself to its new position, after which there will be no further tendency to recurrence. It is important not to add to the amount of scar tissue in straightening the limb, so that in cases of great resistance it is better to extend gradually than to attempt to do too much at once. In such circumstances the Turner splint already described will be of great use. When straightening is complete, it is maintained by the use of a back splint for, say, three months. The splinting is then omitted for gradually increasing intervals, so long as the full range gained can be kept up by voluntary movements. Any reduction of the range is a sign that equilibrium of the scar has not yet been reached, and that a further period of full constant extension is necessary. In suit-

able cases much time may be saved by complete excision of the scar both of the skin and the underlying region. A plastic flap may be brought from one side of the wound to cover the raw space, or, in the case of the elbow, a generous flap may be turned up from the abdominal wall and stitched over the gap. The pedicle remains attached to the abdomen for a few weeks until the flap is well joined and new vessels have been formed, when it is detached by stages to ensure the vitality of the flap. If primary union has been attained, no recurrence of flexion deformity is to be expected, and active and passive movements may be proceeded with at once.

Bony Block.—This is most often found in the bend of the elbow, a piece of bone lying in front of the lower end of the humerus and preventing flexion. It can usually be removed easily by operation. If, as is generally the case, the block is firmly fixed and needs chiselling, a raw bone surface will remain, and it is well to cover this with a flap of deep fascia taken from the thigh. This will take the place of periosteum in preventing the infiltration of muscles with osteoblasts which might lead to new bone formation. The joint is put up in full flexion after the operation, and kept in this position until healing is complete. It is then let down by stages.

Open Operations on Joints.—Those of special importance in connection with the subject under discussion are: (*a*) Excision, to produce a mobile joint or to obtain ankylosis in a good position; (*b*) Arthroplasty, to render a joint mobile; (*c*) Arthrodesis, to obtain fixation of a mobile joint.

In the class of cases under review, *excision* is but rarely indicated. The elbow is the only large joint in which mobility may be obtained with advantage by this method. Here *arthroplasty* may be used as an alternative. This operation will yield a fair range of movement and a strong joint. A well-planned excision at a late stage will produce a better range of movement, but sometimes at a small sacrifice of strength. In the shoulder and wrist better functional results can be got by obtaining stiff joints in a good position than by any attempts at mobilization by excision or arthroplasty. In these joints a linear or wedge-shaped osteotomy near the joint will restore a good position more simply and satisfactorily than an excision.

In the lower limb, stability and weight-bearing are the chief requirements, and operations to mobilize will very seldom improve function. Sometimes a wedge-shaped excision of the knee-joint may be needed to obtain a stiff, strong joint in the straight position. Deformities of the hip or ankle are usually corrected better by a linear or wedge-shaped osteotomy near, but not through, the joint.

Arthrodesis, or joint fixation, may be needed at the shoulder or wrist for flail joints, and also in the former for fixation in some cases of fibrous ankylosis. The adjacent surfaces are made raw, and fixed in position by nails, screws, or wire.

Ankylosis.—Bony ankylosis in a good position is as a rule best left alone. Only in the case of the elbow-joint may mobilization be considered worth while. If the position is bad, correction is to be obtained by one of the means referred to. Fibrous ankylosis will nearly always lend itself to manipulation into a good position. As has been stated, judicious manipulation may sometimes lead to improvement in mobility.

In all cases where ankylosis is inevitable, a faulty attitude must be corrected so that stiffness is maintained in what is the best position for subsequent function. If there is already complete fixation in a bad position, this is to be altered to a good one by one of the methods referred to.

The *shoulder-joint* is in its best position with the humerus abducted about 70 degrees from the side, the scapula being in its normal vertical position. The humerus should also point somewhat forward. The position can be illustrated in the healthy subject by placing the tip of the middle finger over the most prominent point of the opposite clavicle and raising the arm nearly to the horizontal. With a stiff shoulder-joint in this position, play of the scapula will allow the arm to be brought well above the horizontal in one direction and down to the side in the other. It should be emphasized that it is not enough to bring the arm up to this position, but it must come to this point when the scapula is in the normal vertical position.

It is less easy to dogmatize about the best position for a stiff *elbow*. The wishes of the patient should be considered, but an angle of about 100 degrees is most generally useful. The patient is then just able to feed himself and still have a useful reach. Often the question becomes unimportant, as a good movable joint can be obtained by operation.

The rule for the *wrist-joint* is definite. It should be stiff in the dorsiflexed position: function both of flexion and extension of the fingers is then infinitely better than when the wrist is straight or flexed.

The *hip-joint* should be fully extended, slightly abducted, and slightly rotated outward. This equalizes the practical length of the limbs as far as possible, and gives the best stability, standing attitude, and walking gait.

The *knee-joint* should be fully straightened. Slight flexion might be better if it could be maintained, but if this attitude is attempted there is always a well-recognized tendency to the recurrence of flexion deformity.

The *ankle-joint* should be fixed with the foot at right angles to the leg, so that when the patient is standing with his feet together his weight is distributed equally between the heel and the forepart of the foot. Deviation in either direction from this position is equally unsatisfactory.

The *mediotarsal joint* should be slightly inverted, to avoid a tendency to flat-foot.

AFFECTIONS OF INDIVIDUAL JOINTS.

The principles enunciated in the foregoing remarks are those which the writer has made use of in the treatment of joints whose function has been interfered with by gunshot injuries. A brief summary will now be made of the method of their application to the common disabilities found in the large joints of the body.

FIG. 169.—Bandolier shoulder-abduction splint.

SHOULDER-JOINT.

Bony Ankylosis.—Adduction deformity is common. This may be regarded as slight if the patient can already raise the arm to the horizontal by scapular movement. With greater degrees of adduction a wedge of bone is excised from the outer aspect of the surgical neck, to bring the humerus out to an angle of 70 degrees from the scapula. The bandolier shoulder-abduction splint (*Fig.* 169) is retained for six weeks

Fibrous Ankylosis.—The above-named position is obtained by manipulation. Over-correction should at first be reached, to allow for sagging, and a right angle between humerus and scapula may be aimed at for the time. The splint will be needed for at least three months. After two months it may be gradually lowered as a guard against recurrence. The play of the scapula will maintain a good angle between it and the humerus. If this angle tends to become reduced below the final aim of 70 degrees, longer support will be needed. If the fibrous ankylosis is too strong to allow of manipulative correction, the operative treatment should not be by cuneiform osteotomy, but by arthrodesis.

Arthritis with Limited Movements.—If the ideal position (70 degrees between humerus and scapula) is included in the range of movements, no treatment is indicated. If not, the case is to be treated as one of fibrous ankylosis.

Extra-articular Adhesions.—Mild cases are treated by manipulation once through a full range, followed by active and passive movements, combined with massage and baths. Axillary scars are excised and the raw surfaces closed by plastic flaps ; or, as an alternative, they may be treated by applying the abduction splint in as open a position as the contracture permits, and then gradually stretching the scar by adjustment of the splint. Many cases with the massive deep-seated adhesions following wounds and suppuration, will not yield readily to manipulation. In these circumstances the best position is reached, and the future treatment is as for fibrous ankylosis.

Flail Joints.—The deltoid muscle is usually stretched and useless. The arm should be placed as high as possible on the abduction splint to relax this muscle to allow of recovery of its tone. The end of the shaft of the humerus should be brought into contact with the glenoid cavity or its remains, to allow shortening of ligaments. If good apposition cannot be thus maintained, it can be brought about by abandoning abduction, and slinging up the humerus in a vertical position by adhesive strapping passed round the tip of the olecranon and over the top of the shoulder, as in treating acromio-clavicular dislocations. By one of these means the deltoid is kept relaxed without intermission for three months. Massage and faradism may be used as far as splinting permits. If these methods fail to bring about a stable joint, arthrodesis should be performed, and the humerus and scapula fixed together at an angle of 70 degrees.

Open Operations to Mobilize the Shoulder-joint.—Excision or arthroplasty is sometimes performed on this joint, but the results are only fairly good, and the subsequent function is rarely equal to that of a strong joint ankylosed in the best position. An effort to obtain the latter is therefore the method of choice.

Elbow-joint.

Bony Ankylosis.—Unless special precautions have been taken, this usually occurs at about 130 degrees. This does not allow the patient to reach his head and neck for dressing or feeding. Excision to obtain mobility is advisable. The bone removed should just include the articular surfaces of the radius and ulna below, and the tips of the epicondyles above. It is advantageous to cut through the humerus obliquely downwards and backwards, so as to avoid a broad surface which might again become ankylosed with the upper ends of the radius and ulna. The limb is put up in full extension on a long gutter-splint for a week, then brought into full flexion, and retained by a neck-to-wrist sling. The sling is slackened little by little so long as good active power is maintained. Massage and faradism may be used as soon as the wound of operation is soundly healed. Passive movements are rarely needed, but active movements within the range permitted by the sling should be encouraged when healing is sound.

Fibrous Ankylosis.—This will be the general result of an arthritis of the joint. The operations of excision or arthroplasty are available in case of need ; but unless the ankylosis seems very firm, the effect of manipulation should be tried, as this joint lends itself to the treatment, and a fair range of movement is often obtained. Since

ankylosis in an approved position is not the only prospect, it is not necessary to stop when this position is reached. If the joint yields easily, it may be possible to reach full flexion at the first attempt. The wrist is slung to the neck with the joint flexed, and kept at rest until any reaction has subsided and pain has disappeared. The sling is slackened little by little as previously described. An ultimate active range of at least a few degrees is to be expected, and if this is round about the right-angled position, the functional result is very fair, and may prove satisfactory for the patient's future needs without the necessity of an open operation to mobilize.

Sometimes the resistance to manipulation is considerable, and it is then not to be pushed too far. A slight movement followed by rest or the use of the Turner splint with screw adjustment, and further small movements at later dates, are indicated. Too much time is not to be wasted in unpromising cases if the patient is prepared to have excision done.

Arthritis with Limited Movements.—If these include an angle of 100 degrees, the result may be thought good enough to leave to time. The use of the Turner splint is likely to be valuable here, and avoids the danger of interference with the range already present.

Extra-articular Obstructions.—Scars in the bend of the elbow, and bony block, are dealt with in the way already described. Slight adhesions are broken down by putting the joint once through its full range, following with active and passive movements as soon as swelling and pain have gone. The plan of slinging in full flexion, and letting down gradually, is applicable in these cases as well as in the more serious cases of gunshot-wound adhesion already referred to.

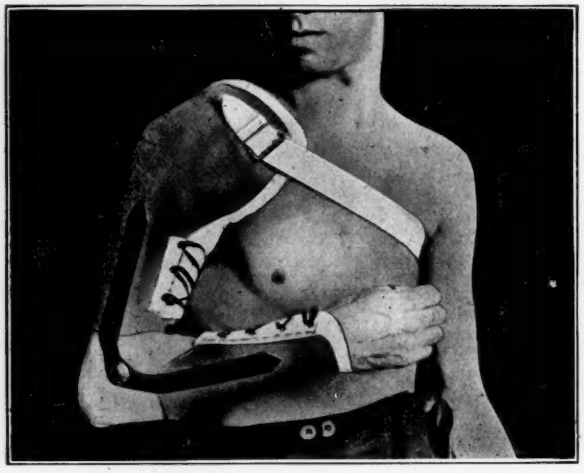


FIG. 170.—Jointed poroplastic splint for a flail elbow.

Limited Extension.—This condition is present in nearly all cases, apart from the question of contracted skin scars already discussed. The disability is comparatively a slight one. Manipulation does not yield good results. The most promising line of treatment is by gradual stretching with the Turner splint. Generally speaking, attention is to be concentrated on obtaining flexion. Time and occupation will often do much to remedy the limitation of extension, and gravity will also act in this direction.

Flail Elbow.—This is the result of too wide an excision. Function is often extremely bad. No stability can be obtained by muscular effort, and the limb is almost useless. An attempt is to be made to obtain contraction of the over-stretched soft parts by slinging the wrist to the neck and applying a figure-of-eight bandage over the joint to draw up the slack. The bandage may be removed daily for massage and faradism, but the wrist sling should never be relaxed, lest all the good be undone. This treatment for three months may lead to decided improvement, and enable the patient to flex the elbow voluntarily. The sling may then be abandoned during periods of activity. Failing improvement, the case may be treated by appliance or operation. A jointed poroplastic splint has been used, with a stop at the elbow preventing extension beyond a right angle, but allowing flexion (*Fig.* 170). This has afforded some relief and allowed of light occupation. Operation may be directed to fixation of the joint at a chosen angle by arthrodesis, or to strengthening the joint by forming new lateral ligaments from portions of fascia lata from the thigh.

Radio-ulnar Joints.

Loss of supination is common in injuries of the forearm, both from fracture and wounds of soft parts. Pronation is the position of rest, and is that naturally assumed during periods of inactivity. Full supination is to be aimed at in treatment. This may be reached by manipulation, and maintained by an interrupted gutter-splint with arm and forearm pieces. The forearm gutter is twisted in the direction of supination, and an anterior gutter similarly twisted is applied, extending from the elbow to the palm. Massage and faradism are used, and the splinting is maintained until equilibrium between pronators and supinators is established, or until the joint is stiff in supination. The natural tendency to pronation will prevent too great a final degree of supination, except in the case of bony ankylosis, when a half-way position must be finally reached.

Wrist-joint.

The disability directly due to stiffness of the wrist-joint is comparatively small if the joint is in an advantageous position, namely, that of full dorsiflexion. This point must be strongly insisted on. Not only does it lead to the best action of the flexors and extensors of the fingers, but the hand is in a better position for manual occupations. It is rarely necessary to be anxious about mobility. The joint is got into full dorsiflexion, and any future possible range of movement can be left to nature. Stiffness has nearly always been reached in the straight or flexed position, and this must be corrected in all cases. Bony ankylosis is met by linear or wedge osteotomy through or near the joint. Other causes of stiffness can be met by manipulation. Resistance is often very great, and will then call for the use of the Thomas wrench with ether anæsthesia. The process may have to be repeated in stages until full dorsiflexion is gained. Some form of the short wrist-splint is used to maintain the position. The palm and forearm portions should be bent to a right angle. The size of the palm portion may at first be necessarily so long as to interfere with the metacarpophalangeal flexion movements, and should be shortened by cutting or changing the splint when a good position has been assured. In some cases it is well to incorporate the splint in a plaster casing, as it may be difficult otherwise to maintain the proper position. Massage and exercises should be used for the finger movements during the wearing of the splint, which may be necessary for several months.

Fig. 171.—Morton's wrist splint.

Flail Wrist.—The disability is very great. The hand is displaced forward, and both flexors and extensors of the fingers and wrist are put out of action. Operation for fixation is the only possible procedure. The lower ends of the radius and ulna are exposed and freshened. Holes in the carpus are gouged for their reception, rather toward the back, so as to dorsiflex the hand. Nails are driven in through incisions on the palmar aspect of the carpus, engaging the radius and ulna, and keeping up the dorsiflexed position. The short wrist-splint will be needed for at least three months.

Dorsiflexion and Supination Splint.—Sometimes supination and dorsiflexion are needed at the same time, not only in nerve palsies but in joint injuries. Morton's wrist-splint is most valuable here (*Fig.* 171); supination is maintained by a sling to the

bar which points anatomically forwards from the front of the inner side of the splint; dorsiflexion is provided by the shape of the splint, into which the forearm and hand fit naturally.

Hip-joint.

The chief concern is to obtain a stable joint in a good position. Efforts to mobilize are rarely indicated.

Bony Ankylosis.—There is usually flexion and adduction deformity. This is best corrected by a wedge osteotomy through the lower part of the great trochanter. The patient is fixed on the double Thomas abduction frame for six weeks, after which he may be allowed to walk. It is essential that the position obtained should be one of full extension, slight abduction, and slight eversion.

Fibrous Ankylosis and *Limited Movements from Arthritis.*—These are treated by manipulation into the best position. The joint is maintained in this position, on the abduction frame for six weeks. The patient may then be allowed to walk gradually. Any possible final range of movement is best left to natural improvement in the course of walking exercise.

Extra-articular Adhesions.—If *x* rays show a normal joint, and particularly if some movements of the joint are perfectly free, manipulation may be undertaken in hope of a movable joint, further treatment being on the lines already indicated for other joints. If great resistance is found, or if grating on movement suggests trouble within the joint, rest in abduction and extension will be needed, as in arthritis.

Bony Block.—This may be limiting abduction. It should be either removed or detached, and the limb fixed in full abduction on the abduction frame for several weeks.

Flail Joints.—A destructive wound of the joint may lead to a practical loss of its stability, with telescope action of the thigh on the side of the pelvis. For perhaps a year or more it is advisable to treat this in a palliative manner by applying a Thomas caliper which will enable the patient to walk fairly well. If fixation is desired later, this will be obtained by an open operation to freshen the opposing surfaces and attach the upper end of the femur to the side of the pelvis in slight abduction.

Coxa Vara.—This may occur from mal-union of the neck of the femur. It is treated by cuneiform intertrochanteric osteotomy, followed by rest on the abduction frame until consolidation is complete.

Knee-joint.

Deformities.—Genu valgum and varum are due to mal-union of fractures of the thigh and leg. Their treatment, which is on recognized lines, hardly comes within the scope of this article. Genu retrorsum, or 'back-knee,' needs special mention, as, in addition to the mal-union which is the primary cause, there is a secondary stretching of the posterior ligament of the joint. It is treated by raising the heel of the boot and applying a knee cage (*Fig.* 172) with a stop to prevent full extension. This may be used for a year. If operative treatment is then required, it will consist in a wedge osteotomy at the back of the lower end of the femur, followed by splinting in flexion until union is sound.

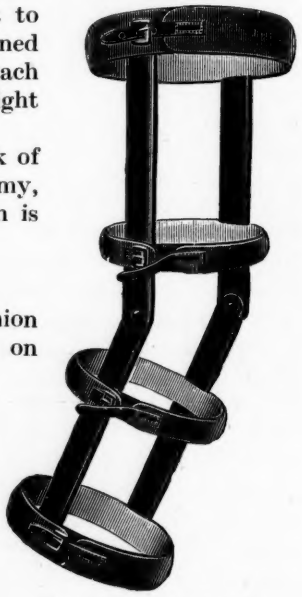


Fig. 172.—The knee cage.

Bony Ankylosis.—Open operations to mobilize a stiff knee-joint have not had very encouraging results. The general aim in ankylosis, therefore, is to restore a good position—viz., that with the limb fully straightened. A wedge-shaped excision is the line of treatment recommended in the rare cases where ankylosis has been allowed to occur in a flexed position.

Fibrous Ankylosis.—This may be so firm that removal of a wedge may be needed,

as in bony ankylosis. Milder forms can be corrected by manipulation. If there is any backward displacement of the tibia on the femur, open division of the hamstrings will usually be advisable. This is done a few weeks before straightening is to be attempted. It should be remembered that the knee is not a true hinge-joint, and if straightening is made without freeing the joint surfaces, the tibia will not roll round to the end of the condyles of the femur, but will pivot on its own anterior edge, which will remain attached too far back on the condyles, causing a posterior displacement. With the patient lying on his face, further flexion of the joint is first made to free the front part of the attachment of the tibia to the femur. Full extension may then be possible with the bones in their normal relationship. If not, flexion must again be made with a well-padded band in the flexure of the knee—the ends of the band being held over the lower end of the table—to act as a fulcrum. By this means the tibia can be made to slide over the condyles, and correct straightening be obtained.

The foregoing remarks apply to cases with powerful and otherwise immovable adhesions. Milder cases may be straightened without great difficulty. Apart from the dangers of suppuration, it is very rarely bad practice to straighten a bent knee, whatever its cause. When it is a question of bending a straight knee, the most careful judgement is required, as this will only be done in the hope of a gain of mobility. In a case of arthritis it can never be useful to bend forcibly. If the arthritis is of so mild a type that some movement is hoped for, this is to be attempted by the use of the Turner knee-splint—resembling the elbow-splint shown in *Fig.* 168—or by allowing the patient to walk, when natural movements will in course of time bring about as much improvement as is practicable.

Extra-articular Adhesions.—These will usually leave a limited range rather than full fixation. Scars at the back limiting extension may in slight cases be treated by manipulation into the straight position; the patient is then allowed to walk in a Thomas caliper for a few weeks, after which active movements are permitted. More severe scars, whether of skin or deep structures, are better treated by gradual stretching. This may be carried out with the Turner splint, a malleable back splint, or a Thomas bed splint, according to the degree of flexion. The larger degrees are put into the Turner splint; intermediate cases have the back splint applied slightly straighter than the limb, and adjusted by stages as the limb conforms to the line of the splint; and small degrees are treated by the Thomas bed splint, with extension from above the knee and bandages across from side to side in front of the thigh and behind the leg. When the limb is straightened by any of these means, the patient is allowed to walk in the Thomas caliper for three months, a back splint being applied during rest. After this time recurrence of deformity is not to be expected, and active exercise and movements are begun, a splint being used at night until full voluntary range is assured. Massage and baths to improve the circulation and loosen scars are valuable adjuncts to treatment during the whole period of correction.

Scars in front limiting flexion are, in war injuries, rarely slight enough to yield to the breaking down of adhesions and free mobilization. The Turner splint is most suitable here. It is put on in full extension, and gradually flexed. When a range of about 45 degrees has been gained, the splint may be abandoned. Massage and active exercises are started, and the patient is allowed to walk. Once a start has thus been made, walking with normal swing of the knee is possible, and the range will gradually increase as fibrous tissue becomes absorbed.

Ankle-joint.

The common deformity is equinus or dropped foot, arising from many causes affecting the joint directly or indirectly. Simple cases from extra-articular lesions may sometimes be corrected by massage and exercises; but the vast majority from all causes are to be treated by immediate correction, with lengthening of the tendo Achillis. Transverse division of the tendon is usually bad in adults, as recovery of strength is retarded. The method of subcutaneous lengthening is completely satisfac-

tory. The tendon is cut half-way through in opposite directions at an interval of about 1½ inches. The foot is then dorsiflexed forcibly, if necessary with the aid of the Thomas wrench, when the intermediate portions of the tendon slide upon each other in the direction of lengthening. The foot is put up in slight over-correction on a shoe splint (*Fig.* 173). Weight-bearing is usually possible in about three weeks. Any tendency to recurrence of deformity is met by a retentive apparatus. The writer has found the ' drop-foot splint ' (*Fig.* 174) quite satisfactory. A short caliper is used, ending above at the upper part of the leg, and below in transverse pins which fit into sockets in the heel of the boot. Flanges fixed to the heel project behind the side bars and allow dorsiflexion while preventing plantar flexion beyond a right angle.

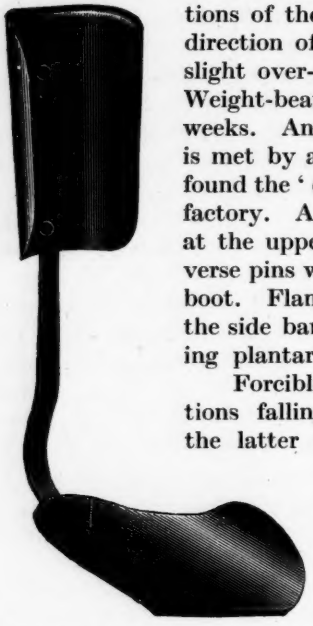


FIG. 173.—Malleable shoe splint.

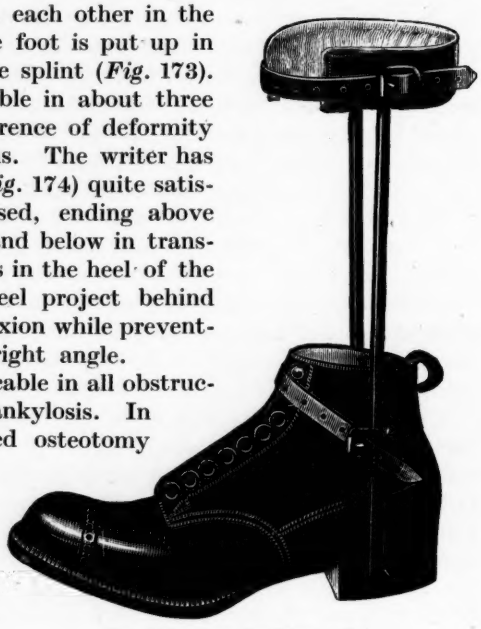


FIG. 174.—Drop-foot shoe splint.

Forcible correction is applicable in all obstructions falling short of bony ankylosis. In the latter case a wedge-shaped osteotomy of the lower end of the tibia and fibula is needed in addition.

The aim, therefore, in deformities of the ankle is to obtain a stable foot. The actual result may be even better, and end in a movable ankle-joint. When this is practicable, it is to be gained by use of the foot in walking after correction has been made.

MEDIOTARSAL JOINT.

Organic deformities of varus or valgus may occur from mal-united fractures and other causes. Their treatment is on the well-recognized lines of that used in civil practice, and needs no special description here.

CONCLUSIONS.

1. Gunshot injuries generally lead to very severe forms of obstruction to the normal movements of joints.

2. Manipulation has its chief use in the correction of deformities, and in changing the position of a joint from one in which function is bad to one in which function is at its best if permanent stiffness is to be the final result.

3. Improvement of mobility is more likely to be gained by slight movements followed by periods of rest, or by slow stretching of contracted parts—in other words, by gradual change of position—rather than by forcible movements through a large range.

4. Open operations to obtain mobility are rarely advantageous except in the case of the elbow-joint, where they are usually satisfactory.

5. Massage and baths are valuable adjuvants to improve circulation and aid in the dispersal of scar tissue.

6. Passive movements have very limited value, and are often harmful.

7. Active movements, especially those of normal use and occupation, are most valuable, and will often do more to increase mobility than any surgical means at our disposal.

UNUNITED FRACTURES, WITH SPECIAL REFERENCE TO GUNSHOT INJURIES AND THE USE OF BONE GRAFTING.

By ERNEST W. HEY GROVES, Bristol.

This paper deals with a series of 60 consecutive cases treated by the author during the last two years, and refers almost entirely to gunshot injuries. From a practical point of view I have thought it better to direct attention to an unselected series of cases, pointing out the difficulties of treatment and the causes of failure, rather than to attempt a literary review of the work of other surgeons. At the present moment the material for the latter attempt is lacking, owing to the fact that only small groups of cases have been published. On considering one's own work, and in discussing the matter with others, one derives the impression that a general feeling of discouragement and failure has prevented publication: but further reflection makes it an obvious duty to enquire into the whole matter, in order that the causes of such failure may be understood, and avoided or overcome in the future.

I. REMARKS ON THE CAUSES, INCIDENTS, AND NATURAL RESULTS OF UNUNITED FRACTURES.

There are certain obvious causes of non-union of fractures, and others which are more obscure, depending upon altered vital conditions of the bone-producing cells which are, at present, matters, of speculation rather than observation. I propose in this paper to deal chiefly with the obvious causes, which could be recognized in all the cases in the present series.

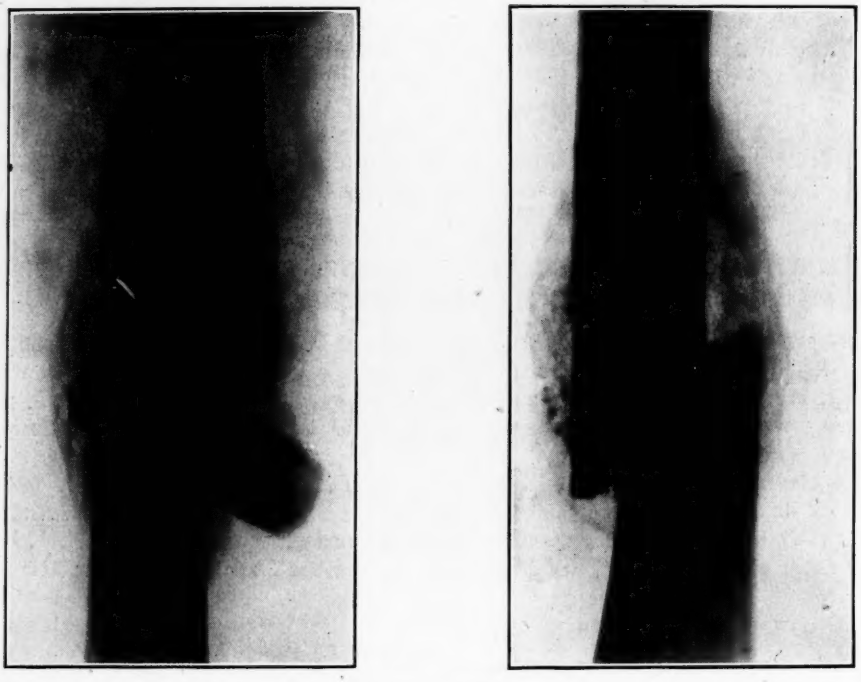
Such causes are four in number, viz.: (1) *Primary loss of substance* (34 cases); (2) *Necrosis or secondary loss of substance* (3 cases); (3) *Displacement, with intervention of soft parts* (21 cases); (4) *Eburnation or sclerosis* (2 cases).

The incidence of these causes in relation to various bones is shown in the following table:—

Bone	Loss of Substance	Necrosis	Displacement	Eburnation	No. of Cases
Radius	10	1	2	—	13
Ulna	8	—	3	1	12
Radius and ulna ..	—	1	—	1	2
Humerus	9	1	3	—	13
Femur	3	—	13	—	16
Tibia	4	—	—	—	4
Total ..	34	3	21	2	60

1. Loss of Substance as the most important Factor in the Production of Non-union of Gunshot Fractures.—This cause is the most important, and accounts for more cases than all the others put together, viz., 34 (56·6 per cent). In the bones—e.g., the radius, ulna, and tibia—where there is another parallel bone which maintains the length of the limb and prevents contraction from bringing about a closure of the gap, the reason for loss of substance leading to non-union is obvious. Whatever may be our conceptions as to osteogenesis, we cannot be blind to the fact, that in the adult a gap in one of the long bones remains unfilled by new bone in a large number of cases. Neither the periosteum nor

the cut ends of the injured bones produce any appreciable callus repair. In fact I would go so far as to say that I have seen no evidence of the reconstruction of the diaphysis of an adult bone when a considerable portion of it has been removed. And this in spite of the fact that I have been looking for such evidence very closely, and asking for it from others. It is impossible to say to what extent the loss of bone is actually occasioned by the original wounding missile, or how far it has been due to primary surgical interference, or to later sepsis ; but there can be no doubt that in a great many cases the bone has been very freely sacrificed by operative attack, as is shown by clean sawn ends, and also by statements on the field cards, such as "Bone fragments freely removed," etc. It would be quite unfair to criticize such treatment without knowing the circumstances which appeared to justify it, and I have no doubt that rapid clean healing has often been promoted thereby, and that limbs and even lives have been saved which would have been lost



FIGS. 175, 176.—Right and left femurs of an officer who fractured both thighs and his skull in a flying accident. The photos are taken four weeks after the accident, and illustrate the rapid formation of callus under the influence of constant movement. The patient was delirious and violent for all this period, and was treated by 20 lb. weight extension applied by tibial transfixion to each leg. He obtained a perfect functional result, and was able to play tennis four months after injury.

by more conservative methods. But it is useless to shut our eyes to the fact that this free removal of bone does almost inevitably lead to an ununited fracture which causes a very prolonged loss of function and which requires a most difficult and uncertain operative treatment for its final restitution.

It must be observed here that the present series of cases does not include any which have recovered apart from definite reconstructive operations, the reason being that one cannot draw the line between many cases of merely delayed union and those which are really cases of non-union. Thus, we have had a large number of cases of fracture the union of which was delayed by sequestra, and in which rapid union took place after the removal of the dead bone. This observation leads to the conclusion that, whilst primary removal of all loose fragments is likely to cause an ununited fracture, if the case is freely drained and properly immobilized, and left until the dead bone is naturally differentiated from the living, before the removal of sequestra, natural union will generally occur.

It is a monstrous misuse of terms and a flagrant begging of the question to call all loose fragments of bone in a comminuted fracture 'sequestra,' and to teach that primary subperiosteal sequestrectomy should be the treatment. I have elsewhere published a sufficiently large series of cases of consecutive gunshot fractures of the femur to demonstrate that the cases of comminution heal with rather greater rapidity than those of a more simple nature, and I have also given experimental evidence to the same effect. The present study of cases in which a large removal of bone fragments has been carried out is the natural complement of the experimental and clinical evidence as to the importance of the bone fragments in bringing about natural repair.

To sum up : Always supposing that free drainage has been secured, with a removal of gross dirt and septic foreign bodies, then the leaving of bone fragments in a comminuted fracture is the surest way of securing natural and rapid repair, whilst removal of these fragments is the surest way of producing an ununited fracture.

I believe that it is extremely rare for a piece of bone to be severed from all vascular supply by trauma, and I use the term loose fragment as implying that a piece of bone is

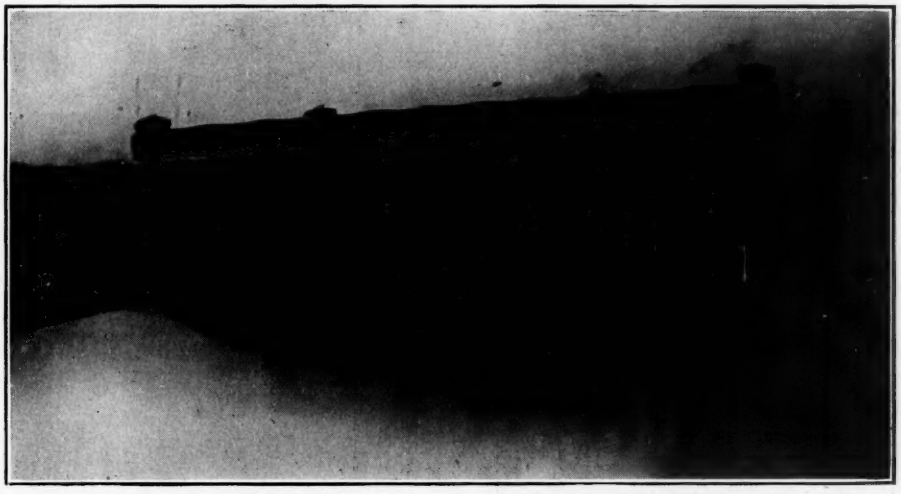


FIG. 177.—Femur of *Case* 47 treated by a bolted plate after seven months' non-union due to displacement. Perfect result, but the plate had to be subsequently removed on account of the formation of an abscess.

separated from the main shaft but not from organically connected soft parts. I have no belief in the value of a piece of bone separated from its blood-supply as an agent of repair, and if such separation is beyond all doubt, then surely the fragment is better away from a septic wound. But it is far better to wait for a few weeks for natural differentiation of dead bone, than to expose and search for sequestra by manipulations which endanger the vascular connections of the fragments in question. Apart from the failure of the wound to heal, there is a ready method of recognizing 'dead bone' in a fracture, and this is usually available in four to six weeks after the receipt of the wound. It is by means of the x rays. The region of the injured bone rapidly undergoes changes in density, all the living bone becoming rarefied, whilst the dead bone retains its original opacity.

The radius, ulna, and humerus are the three bones which most often exhibit non-union from loss of substance. In the case of the two former, when the fellow bone is intact, the explanation is that contraction cannot take place. With the humerus, it is the weight of the arm which prevents this contraction, and it is not easy to devise a suitable splint or sling which will obviate this whilst allowing of the daily dressing. One of two devices may be employed, either an abduction arm splint in which the humerus is kept almost in a horizontal plane, or else a special wire cradle splint by which the forearm is slung to the shoulder. The former is suitable for fractures of the upper, and the latter

for those of the middle and lower, portions of the shaft. The tibia is not so frequently the seat of an ununited fracture from loss of substance, because usually the fibula is also broken either primarily or secondarily, and this allows of the apposition of the broken surfaces. In the case of a small gap in the tibia with a large anterior wound which will make grafting difficult, it is better to do an osteotomy of the fibula at an early stage, so as to get the tibial fragments together before sclerosis has occurred. The femur is rarely the seat of an ununited fracture due to a loss of substance, because the strong contraction of the thigh muscles brings the bone ends together, and if the loss is not more than 1½ in., and if care be taken to secure correct alinement, I think that this natural mode of cure should be encouraged.

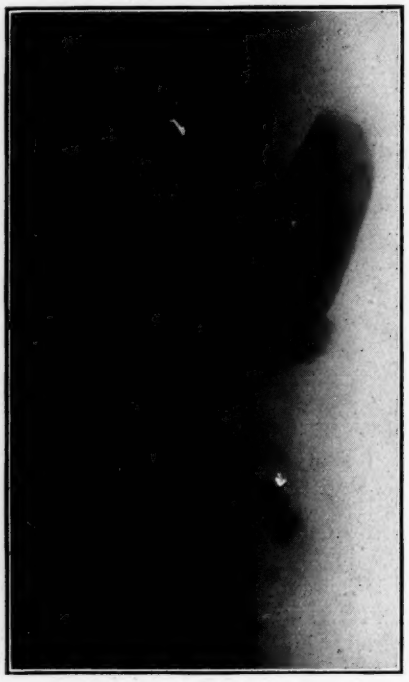


FIG. 178.—Femur of Lt. T. before operation.

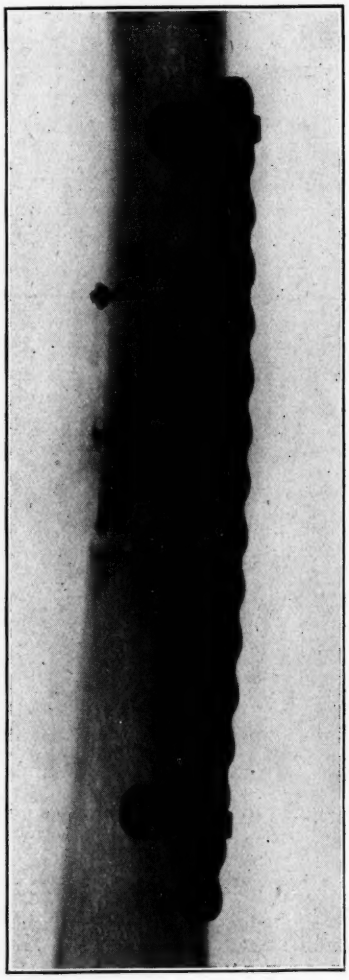


FIG. 179.—Same bone after operation. The large loose fragment was twisted round and had to be replaced. It was bolted to the upper fragment, and this was then fixed to the lower by a clipped plate.

2. **Necrosis.**—This may be regarded as a common cause of delayed union, but a very rare cause of non-union. The present series only contains three cases, and it is worth considering the point whether, in each of these, union would not have resulted from mere sequestrectomy. As it was, in all three cases, as healing had occurred for a long time without union of the fracture, a reconstructive operation was undertaken. As a first step in this, the loose fragments of bone were removed, and it was easy to recognize that they were really dead ; also they lay in purulent fluid. In each case the plastic operation failed to achieve immediate success but ultimate union occurred—i.e., healing by second intention. It is now quite obvious that in these cases, and I think probably in all similar ones, the right method of treatment would have been to be content in the first place with

removal of dead bone and granulation tissue, postponing any reconstructive operation until six months after healing had occurred, by which time nearly all such cases would have undergone spontaneous union. A very important point in this connection is the fact that necrosis very seldom affects the ends of the main fragments of a fracture. If these ends became the seat of necrosis, then this would be a common cause of non-union, because it is from them that natural repair must take place. We often get cases in which the ends of the main fragments have been sawn off, with the idea, no doubt, of removing infected tissue. But as these bones can take care of themselves, and in the process of throwing off infection also throw out reparative callus, it would seem to be a strong

FIG. 180.—Humerus of *Case* 36 before operation. Note the comminution and atrophy of the bone at seat of fracture.

FIG. 181.—The same bone after step-cut operation, fixed between two aluminium bolted plates. Perfect result.

reason for leaving them alone. It seems to me bad surgery to remove any attached fragment from a comminuted fracture ; but it is still worse to cut off the ends of the main fragments.

3. **Gross Displacement as a Cause of Non-union.**—In 35 per cent of the cases, non-union was due to displacement of the main fragments. Such displacement may bring about non-union in a variety of ways—e.g., the interposition of muscle and tendons ; the wrapping round of the raw bone end in periosteum or fascia ; or the placing of a wide interval between the fragments, which becomes filled with dense scar tissue. Non-union of fractures results from displacement, for the same reason that it does from loss of sub-

stance—that is to say, in each case the wounded bone surfaces are removed too far from one another for a callus bridge to occur between them. It is much less likely to result from displacement than from loss of substance, because the most frequent form of displacement is an overlapping, in which broad contact between the fragments is retained. In other words, if alinement is maintained, union will occur, even if there is shortening; but if there is marked angulation, then the bone fragments become separated by the intervention of soft tissues, and callus bridging is prevented.

FIG. 182.—Radius and ulna of *Case* 26 before operation.

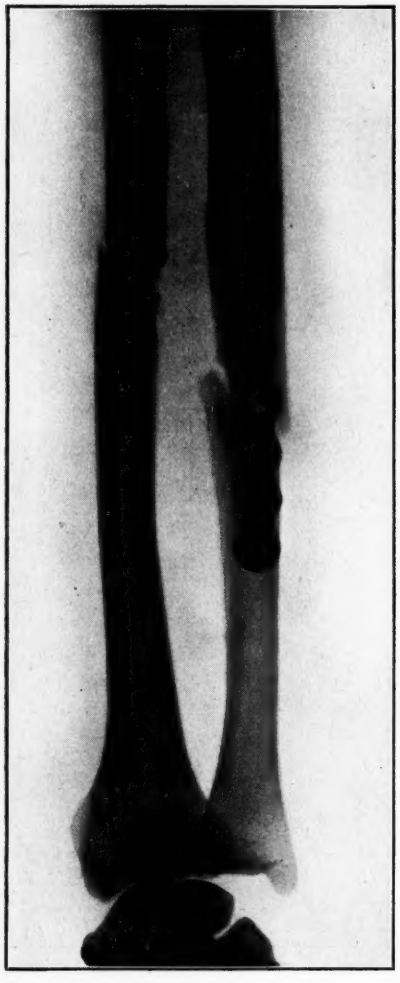


FIG. 183.—Radius and ulna of *Case* 26 immediately after plating.

The most striking instance of this form of non-union is afforded by the femur, which in the present series, supplies 13 out of 21 cases of non-union due to displacement. Three of these were fractures of the femoral neck, and possibly these should be placed in a category by themselves, because the cause of non-union is rather the primary interposition of the joint capsule than gross displacement. I do not think that any postural or splint treatment will prevent non-union in such cases, and a reconstructive operation should be done as soon as asepsis is secured.

Five were cases of fracture just below the trochanters, and in these the upper fragment was so tilted forward and outward that there was no contact with the shaft. Five

were fractures of the middle of the shaft, in which the lower fragment had sagged backwards with some amount of adduction. One was at the lower end, in which the lower fragment was flexed at the knee so as to lie behind the shaft and at an angle to it. All these varieties of displacement non-union of the shaft of the femur are promoted by the limb having been incorrectly immobilized in the first place. It should be placed in the natural position of muscular relaxation—i.e., with the hip and knee semiflexed and the thigh abducted. In this way can the main fragment best be brought into line with the upper piece which is tilted forwards and outwards, or the lower piece which is tilted backwards. Then, if in this position efficient pin extension be adopted, full length as well as alinement will be attained, and under these conditions I have never seen the occurrence of non-union of the femur.

FIG. 184.—Radius and ulna of *Case* 26 eight months after plating, showing non-union of fracture and pulling out of screws.

FIG. 185.—Same case three months after double step-cut operation.

I might mention, in passing, that this transfixion extension is best carried out in the following manner. The *tibia* is transfixed just behind and below the tubercle by a pin 4 in. long and $\frac{1}{8}$ in. thick. The leg, in the position of flexion of thigh and knee, is then slung either to a Balkan splint, Hodgen, or wire cradle, and extension of about 20 lb. applied. Counter-extension is made by a padded perineal band applied round the sound thigh, and this, by tilting the pelvis up on the sound side, assures abduction of the fractured femur. The great advantage of the tibial site of transfixion is that it concerns dense avascular bone, and not the soft cancellous bone of the lower end of the femur. The pin can be left in place for two or three months, where it remains quite firmly. If the transfixion site becomes a septic seton track, it is so superficial that it is easily treated, and it does not lead into connective-tissue planes like those of the thigh. As the main object of extension of the thigh in fractured femurs is to overcome the contraction of the quadriceps and hamstrings, and as the insertion of these is into the heads of the tibia and fibula, the tibial transfixion site is well calculated to act with maximum result upon these muscles.

I am glad to learn from all published accounts that suspension, weight extension, and the flexed position of the joints have now been generally adopted in the Service; but unfortunately many cases are still put up in the straight position, and merely tied to a splint, and I cannot urge too strongly that this involves a great danger of uncorrected displacement and non-union, especially in fractures of the upper and lower ends of the femur.

Apart from these injuries of the femur, there is one other type of fracture in which displacement commonly leads to non-union, and that is in lesions of the shaft of the radius, where the distal fragment is pulled inwards and is liable to become

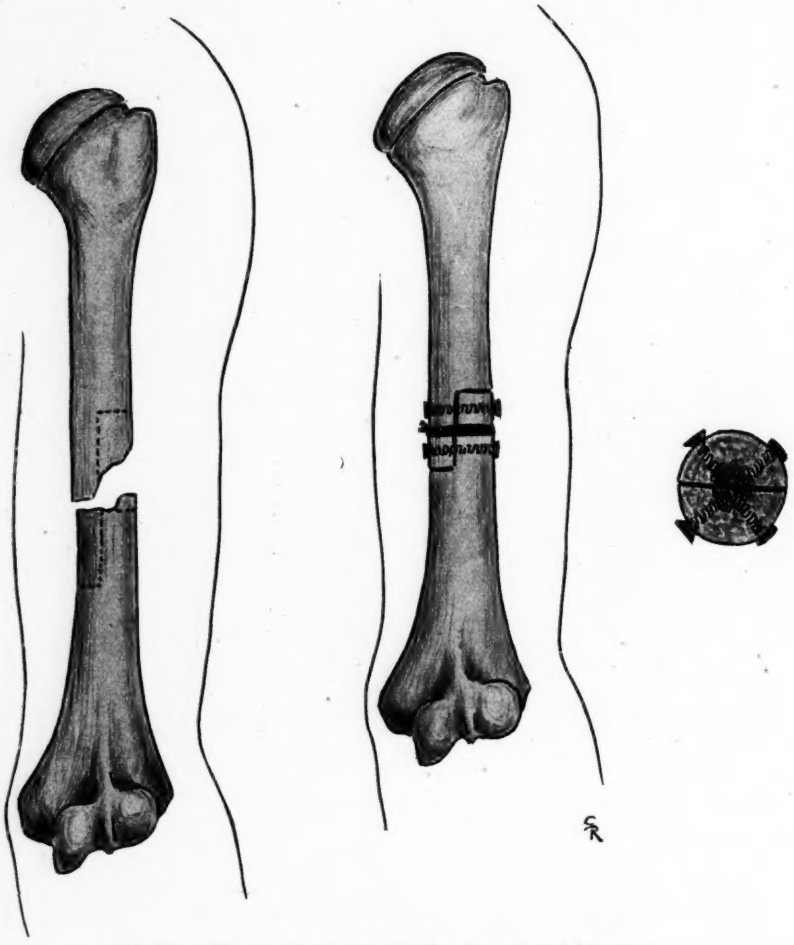


FIG. 186.—Diagram of step-cut operation for ununited humerus.

attached to the shaft of the ulna. Such a case will usually require a reconstructive operation eventually; and whilst primary healing is occurring, all that can be done is to maintain supination of the forearm with adduction of the hand.

4. **Eburnation as a Cause of Non-union.**—The present series contains two instances of this phenomenon. It is so well known as a complication of plating operations that it has been made the basis of the suggestion that all such procedures should be replaced by the sliding-graft operation devised by Albee. I will return to this matter later on in another connection, and in the meantime it is enough to emphasize the fact that operative treatment of fractures may, under certain conditions, be an actual cause of non-union. I have illustrated such a condition experimentally

and the two instances in the present series are also perfectly typical. The ends of the bone are exposed and partly deprived of their vascular supply by separating them from the soft tissues. Then they are fixed to an internal splint, which does not necessarily press the raw surfaces together, but, on the contrary, often holds them apart. The bones, being deprived of the natural stimulus of contact and friction, and having their blood-supply diminished, do not throw out callus in normal amount. Then, when muscular strain is allowed to fall upon the bone, its effect is to loosen the screws in one fragment or the other, and this usually occurs before the delayed callus union has been effected. At this period the bone ends are indolent and eburnated, and non-union is the result. I do not suggest that this is the usual result of plating operations, but it is a sufficiently common one to be a matter of importance. It is likely to occur in proportion to the conditions which favour slowness of callus union. That is to say, it is probable in feeble conditions of vitality and of circulation, in those situations where there is a constant muscular strain tending to angulation, and, above all, when plating is done at a long period after the original injury, when eburnation of the bones has already set in. If I am correct in these statements, then it would follow that plating of the ordinary kind is especially unsuited for the treatment of ununited fractures.

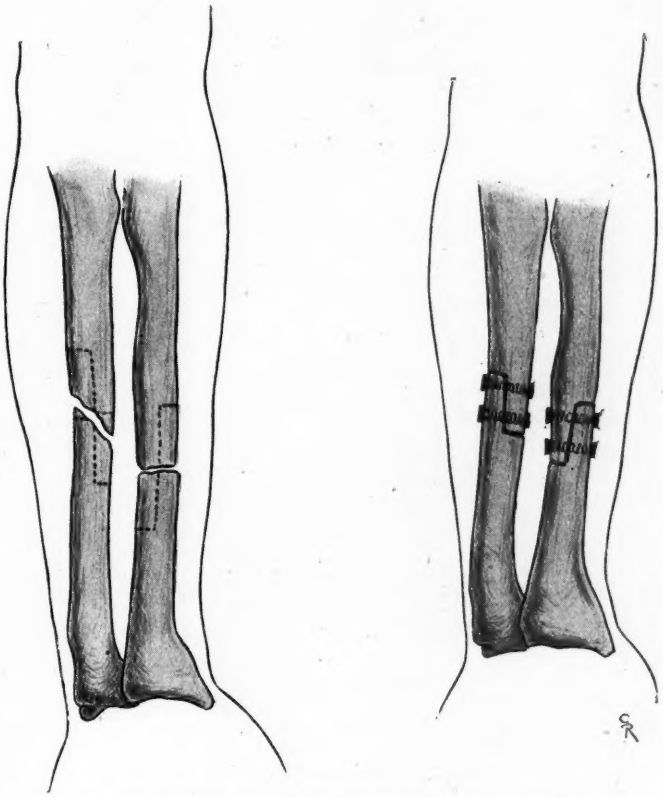


FIG 187.—Diagram of step-cut operation for radius and ulna.

The Influence of Sepsis and Mobility. — It will be noted that I have not included either sepsis or mobility among the causes of non-union of fractures. This is for the reason that, after the most careful consideration, I cannot find evidence of either of these conditions acting in this manner. Of course, a fracture will not unite whilst acute infective inflammation is in progress ; but when this has been checked by drainage and the natural processes of tissue resistance, then the mere persistence of a local sepsis does not cause non-union of the fracture. The more quickly and the more thoroughly sepsis is removed, the quicker and better will be union of the bones. But late union of the bones does occur in the presence of sepsis, and is, indeed, simply a part of the phenomenon of union by granulation tissue.

Neither is mobility of a restricted type a cause of non-union. By restricted, I mean mobility which does not dislocate the ends of the bone from contact with one another. I lately had a remarkable illustration of the way in which mobility actually encourages rapid union. A flying officer sustained a fracture of the base of his skull and a fracture of both femurs. He was put up in two cradle splints with weight extension applied by tibial transfixion ; but for more than four weeks he was very delirious and restless, and in spite of sedatives he moved his legs

incessantly, so that the two weights were pulled up and down on their pulleys with the most menacing regularity. Fortunately his mind made a rapid recovery, and the femurs united firmly in six weeks, whilst he was able to walk in eight weeks, and play tennis in four months. (*Figs.* 175 and 176.) Similarly, I find in all fractured femurs that movements of the knee and hip carried out from the third week onwards, with massage, greatly hasten and assure good union. This can be carried out, when the limb is slung in a semiflexed position and alinement maintained by weight extension, in a way which no other method that I know of allows.

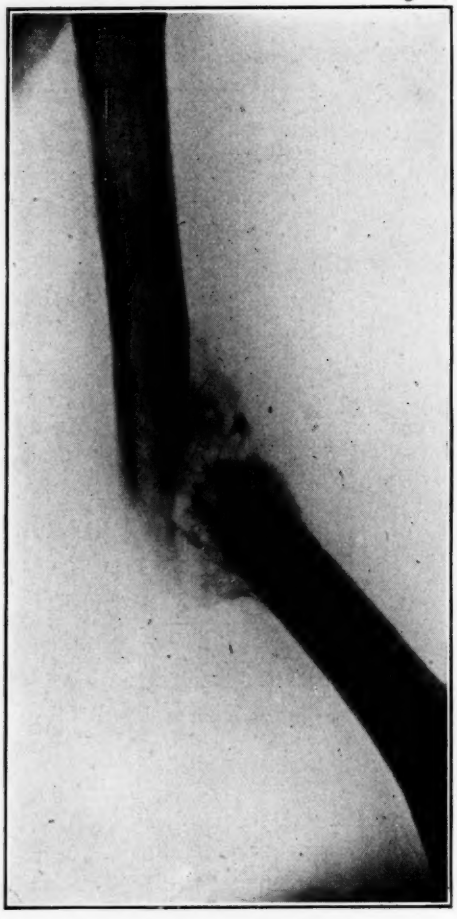


FIG. 188.—Humerus of *Case* 35 before operation.

FIG. 189.—Same bone successfully united by step-cut operation.

One more point may be mentioned in this connection. If an excision of an ankylosed joint is performed, then ultimate mobility—i.e., non-union—will be best secured by absolute rest for several weeks, followed by only the gentlest movements. On the other hand, if anything like forcible (i.e. painful) movements be undertaken at an early stage, then re-ankylosis will probably occur. This is only another illustration of the fact that restricted mobility causes rather than prevents bone growth, whether in the shaft of a bone or at its joint extremities.

The Natural Course of Ununited Fractures.—It is of some importance to inquire what would be the result of leaving ununited fractures to the course of nature. If the ends of the bone are separated by a considerable distance, either from loss

of substance or by displacement, it is almost certain that union will never occur. This for two reasons: first, that new bone is not laid down in adult tissue except as a thin layer covering the bone wounds; and second, that these wounded bone surfaces soon become wrapped round in a dense avascular connective-tissue envelope which seals up the little osteogenic impulse which first existed. It must be admitted, however, that it is extremely difficult to be certain about the behaviour of the bone in any given case, so that it is always wise to wait for a long time before deciding that union is not going to occur by natural means. During this waiting period the various well-known methods of stimulating osteogenesis may be tried. These are—

FIG. 190.—Humerus of *Case* 33 after step-cut operation.

FIG. 191.—Same bone two weeks later, showing the breaking away of the step from the upper fragment. This would have been avoided by the addition of a plate as in *Case* 36, *Fig.* 181.

in their order of usefulness—movement, passive congestion, percussion, and injection of various fluids. In my own experience, the first three of these methods will almost invariably succeed in producing union in all cases where there is actual bone contact between the main fragments, supposing that their application has not been too long delayed. They are quite useless, however, in regard to osteogenesis when there is a large gap between the bone ends, though they do something to preserve vascularity and function.

In all doubtful cases, i.e., where the separation of the bone fragments is definite but small, then decision between expectant and operative treatment must depend upon the amount of deformity which will result from the former, and the prospect of

correcting it by the latter. So long as infection or its results have to be got rid of, and there is definite evidence of recovery of continuity by the bone and of function by the muscles, then the time of waiting is all a gain. On the other hand, if there is no continuity restored in the bone (and this applies especially to single bones, e.g., the humerus or the femur), then prolonged waiting does definite harm. This is due to two circumstances: First, the bone itself undergoes changes which are prejudicial to a reconstructive operation; the fragments always suffer from atrophy or sclerosis, and in each case this involves a diminution both of vascular supply and of bone-forming cells. Secondly, the soft tissues all suffer from the loss of their normal skeletal support; the muscles waste and lose their function, and the nerves are often so dragged upon as to be incapable of conduction. Therefore, whilst I advise waiting where there is prospect of natural recovery, I would deprecate this in other cases where there is great loss of function, deformity, and no prospect of callus union.

FIG. 192.—Humerus of *Case* 34, united over a short ivory peg with successful result.

II. NON-OPERATIVE METHODS OF TREATMENT.

I have already mentioned those means of hastening the union of indolent fractures which are of most service. They are passive congestion, percussion massage, and movements both passive and active. But I do not think that any of these methods are of much avail in genuine cases of non-union—that is to say, in those where the bone ends are separated by dense scar tissue or by soft tissues. Such methods ought to be applied comparatively early in the course of any given case, at a time when cellular proliferation is still a potential factor, and before all bone canals are superficially closed and all intermediate tissue is converted into dense scar. They ought to be regarded rather as methods of prevention of non-union than of cure.

Passive congestion is a method of the greatest possible value in expediting the healing of a fracture. It may be applied in two ways: either by tying a piece of drainage tube above and below the seat of fracture (Thomas); or by the use of a flat rubber bandage applied above the injured portion of the limb (Bier). Each method has its own advantages. Thomas's method produces a more local congestion, but in the forearm and below the knee it has the drawback of tending to displace the parallel bones towards one another. Bier's method produces a more massive congestion, but requires more skill and judgement in its application. It is especially suitable for the forearm or leg bones, and for any case with extensive wounds.

Another method which acts by encouraging local congestion is the application of a light plaster-of-Paris bandage, provided with a window opposite the wound. This should be applied with the limb raised, and when it has set, the limb is lowered and used. Local œdema of the parts at the window is produced, with a temporary increase of discharge. The limb can be used, and this promotes the circulation and also some frictional stimulation of the bone ends.

Deep and percussion massage should be used in all cases where mobility at the

seat of fracture persists unduly. The presence of pain during manipulation is a useful guide in this matter. In the early stages of normal fracture recovery, any attempt to move the bone is accompanied by pain, and such should, in my opinion, be most carefully avoided. Later on, however, if the fracture has assumed an indolent condition, manipulation is painless; and this is an indication that deep massage, and even friction of the bone ends together, should be carried out.

The rôle of *movements* in the treatment of fractures has been emphasized quite rightly by Lucas-Championnière. But movements must be regulated by two conditions: they must be painless, and must not tend to displace the fragments from one another or to alter the alinement of the bone. Passive and active movements, most carefully adjusted for each case, should be carried out as soon as these can be done without causing pain or moving the fragments. Then, when a fair degree of consolidation has occurred, a suitable case splint is applied and purposive functional movements encouraged. I have never seen a case of the non-union of a fracture which could be attributed to such movements, but I have seen many in which delayed union was due to the opposite condition, i.e., to rigid immobility. The great danger of early mobilization of fractures lies in the liability of the bending of soft callus union, and this must be recognized and prevented by suitable splinting or posture.

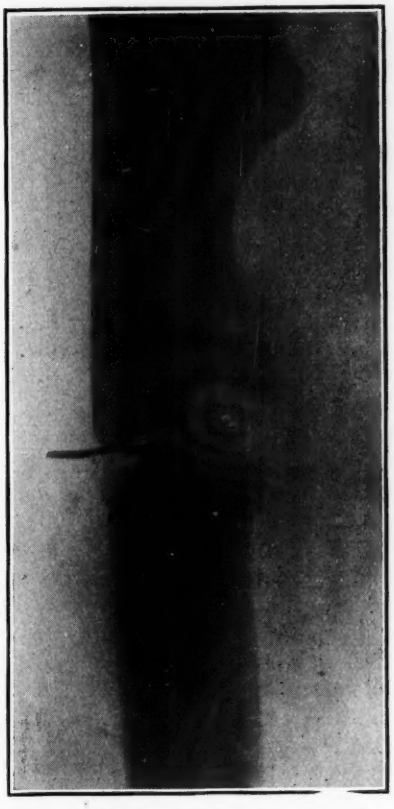


FIG. 193.—Femur of *Case* 49 successfully united over an ivory peg.

There are four situations in which this danger should always be guarded against: (1) In the upper end of the humerus, the bone becomes angulated outwards, and this can be prevented by keeping the arm in an abduction frame. (2) In the radius, there is always a tendency to pronation, which must be prevented by a supination splint taking its bearing above the elbow-joint. (3) At the upper end of the femur, there is a tendency to angulation outwards, and this often persists in gunshot fractures for twelve months after the original injury. It must be fully corrected in the first place by efficient extension in a position of flexion and abduction of the thigh, and then maintained by some form of rigid metal splint on the outer side of the leg, which is firmly fixed above to the pelvis and below to the condyles of the femur. (4) There is a tendency to a backward sagging of the middle of the femur in fractures of the shaft of that bone. This, again, must be first corrected by suitable cradling combined with extension, and then maintained by a light case splint suitably supported to the opposite shoulder. A rule of safety is to use a walking caliper splint for all gunshot fractures of the femur for six months after union has taken place.

Operative Measures which aim at Callus Production without Suture of the Bone.—There have been many proposals to attempt callus stimulation without bone suture. They consist in needling the bone ends, injection of blood or of fibrin, the insertion of magnesium, or the drilling of the fragments. No doubt all these have a certain value; but from a practical standpoint in dealing with really ununited fractures they are unsatisfactory. Based upon experimental evidence they are liable to fail, for the conditions of an ununited fracture are different from those which obtain in experimental conditions; that is to say, there exists a sclerosis both of the

bone and soft parts in ununited fractures which is not present in animal experiments. Clinically, therefore, these methods either do too much or too little; they are superfluous or they are futile. If sclerosis of the tissues is not present, then the methods of congestion, deep massage, and limited movement will suffice; if it does exist, and if an open operation is necessary, then something more certainly efficacious is indicated. Multiple drilling of the bone fragments after removal of the scar tissue is certainly the best of these callus-stimulating devices; but it will only succeed where there has been no loss of bone substance and no gap to be filled.

III. CONSIDERATIONS PRELIMINARY TO OPERATIVE TREATMENT.

In every case of ununited fracture there is one of three principal causative factors—either a gap in the bone, an interposition of soft parts, or an indolence of the bone ends. The last-named factor is one of great importance, because it arises in every case sooner or later, whether it is a primary condition or not. It may actually arise from the other two conditions—namely, want of continuity or the interposition of soft parts—or it may be caused by septic inflammation, which brings about a filling up of the vascular canals of the bone and a covering of its surface with scar tissue. Indolence of the ends of a fractured bone may take the form either of atrophy or sclerosis. Atrophy is most conspicuous when there is a gap in the continuity of the bone, sclerosis when there has been marked septic inflammation. But in either case the condition of the bone ends with which it is desired to bring about union is very unsatisfactory. Either there is a shaft of a bone which consists of a mere thin shell filled with fatty marrow, or else there is a dense avascular substance which is best described as bone scar tissue. Such bones will not throw out callus in the normal way however they are treated, and all the non-operative methods of treatment are therefore likely to fail. Similarly, other methods which merely aim at suture of the bone, without providing for the removal and replacement of this unhealthy tissue, will also fail, and this must be one of the cardinal facts to be borne in mind in the consideration of all operative procedures.

Before describing and discussing the various operative methods which are available for ununited fractures, it will be necessary to consider various conditions of the tissues which exist, especially in cases of gunshot injury, together with some general technical principles. Upon a correct appreciation of these conditions and principles will depend the choice of cases for operation, the determination of the best period for operation, the selection of the type of operation, and finally, in a large measure the success or failure of the operative treatment. These various factors may be summarized as follows: (1) *Latent sepsis;* (2) *Scar tissue* (skin, soft tissues, bone); (3) *Vascularity;* (4) *Functional conditions of muscles, nerves, and joints;* (5) *Aseptic technique;* (6) *Immobilization.*

1. **Latent Sepsis.**—It would be out of place here to enter into the very difficult problem of septic infections of wounds and the possibilities of their sterilization and suture. But it is necessary to emphasize most strongly certain facts which have been repeatedly urged, and which, though difficult to understand, nevertheless lead to plain conclusions.

Whatever may be the possibility of sterilizing wounds of the soft parts and of the bones in the early stages of their existence, this possibility has vanished at a late period. From this it follows: (1) That the most important problem of military surgery still consists in an early and thorough treatment of the wounds so as to allow of primary or delayed primary suture; and (2) That if this has not been done, then a very long interval must be allowed to elapse before reconstructive operations are undertaken, in order that natural processes of reaction against infective organisms may be complete. We have long been familiar with the idea of latent infection, particularly in the case of tuberculosis. We knew that the so-called cure of a tuberculous disease was often only a comparative term, and that any violent trauma such as that entailed by wrenching a tuberculous joint would almost certainly lead to a violent recrudescence of the infective disease. Just so it is with limbs which have for weeks or months been subject to pyogenic infection. In

proportion, probably, to the length of time that infection is known to have existed, will be the period necessary for the infective agent to be eliminated, even after the outward signs of infection—i.e., inflammation or an unhealed sinus—have disappeared. The probability of latent infection and the length of its duration in any given case is in proportion to: (1) The extent of the primary wound and its degree of infection; (2) The amount of scar tissue deposited in the tissues; (3) The length of time during which manifest infection is known to have been present; (4) The extent of bone involvement. This latent infection will be slight and transient in a clean through-and-through wound which has quickly healed, and it will be great and of long duration in an open lacerated wound which has

FIG. 194.—Femur of *Case* 58, ununited after sixteen months. Note the atrophy of the bones.

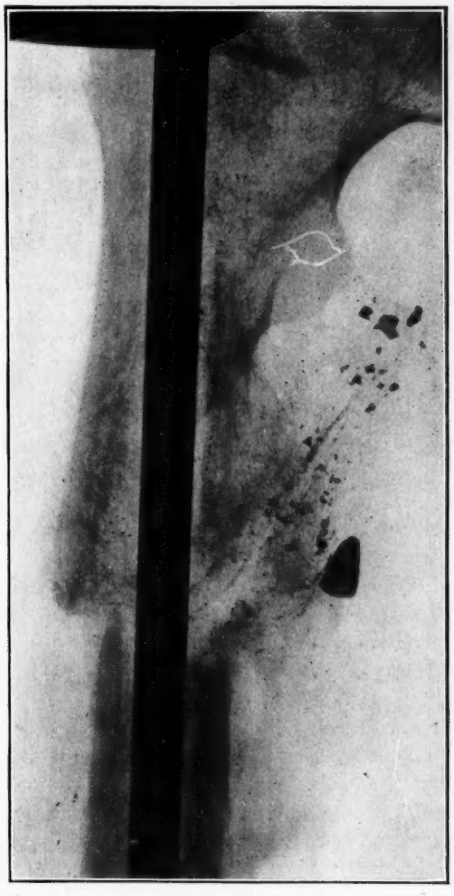


FIG. 195.—The same bone united over a long steel strut introduced from the tip of the great trochanter.

slowly healed with a deposit of much scar tissue; and of all wounds, those which have opened up and comminuted large tracts of bone tissue will be those which harbour latent sepsis the longest.

It has been generally accepted that a period of three months should elapse between the healing of a septic wound and the undertaking of any reconstructive operation. This may be a good working rule, but I think should be regarded as a minimum, to be increased when there has been a large wound, much scar tissue, and much bone involvement. I feel it to be especially incumbent upon me to emphasize these points, because I was originally very sceptical about them, and as a result I have had many failures, which duly appear in the present series. I may briefly refer to some of these cases in this connection.

Case 54.—A fracture of the lower end of the femur, in which the distal fragment was tilted backwards almost at right angles. The patient suffered much pain owing to the pressure of this fragment upon the popliteal nerves and vessels. He had two clean granulating wounds, and a febrile temperature. It was three months since the date of his wound. Through two lateral incisions I restored the alinement of the bone, and fixed it by double bolted plates. The operation was very difficult owing to adhesion between the lower bone fragment and the vessels in the ham, the separation of which caused great bleeding. He developed septic moist gangrene of the foot, and after amputation at the fracture had been performed, tetanus supervened, from which he only recovered after a desperate struggle.

Cases 1, 2, 3, 10, 14.—These are examples of cases treated by bone grafting at comparatively short intervals after the healing of the wounds. Failure followed in all, and either another operation will have to be done, or a permanent disability be allowed to remain.

It may be asked why these comparatively early operations were performed. My answer is, that I thought the occurrence of healing was proof of the end of infection, and that by not delaying operation too long there would be a heightened resistance to infection, and the minimum of atrophy of vessels and muscles. But it is evident that such theoretical anticipations are not borne out by the facts; and until some new method of sterilizing the tissues is introduced, the dominating consideration must remain, that every septic case retains latent sepsis long after healing of the wound, and that any attempt to save time by hurrying on a reconstructive operation will defeat its own object: so that by not waiting for three months at first, one may have to wait for a year or more later, before final success can be achieved.

When the wounds have soundly healed, it is not enough to wait passively for three or four or six months; but during this time active and passive congestion must be encouraged by heat, deep massage, and intermittent bandaging with rubber tubes. The functions of the nerves, muscles, and joints must be retained as far as possible by electrical stimulation and, above all, by purposive movements.

FIG. 196.—Femur of *Case* 57 after five months' treatment on a Thomas splint. The upper fragment was tilted forwards and there was neither contact nor union.

2. **Scar Tissue.**—Second only in importance to autogenous infection by latent sepsis as a cause of failure is the presence of large masses of scar tissue on the surface and in the depths of the wound. Probably the infective agents become encapsuled in the scar tissue, just as happens in the healed tuberculous foci of a phthisical lung. Not only is scar tissue resulting from a septic wound to be regarded as a germ envelope, but also it is a tissue of very low resistance to extraneous infection. The most striking evidence of this is afforded by the behaviour of cutaneous scars after operations. The wound heals by first intention, but if a large skin scar has been left to cover the tissues, then, within a few days, this gives way in part, or altogether melts away, leaving a superficial ulcer. But after all, the skin is only the visible aspect of the scar, and the deep scar in the soft tissues and the bone—whether at the ends of the main fragments or as isolated pieces—must also be regarded as tissue of poor vitality, deficient circulation, and weak resistance. The ideal principle to

be arrived at is to remove all this scar tissue before attempting to reconstruct the bone. In practice it is usually the best plan to do one or more preliminary operations for the substitution of the skin cicatrix and the soft-tissue scars. It is best in the case of a large skin wound to take a pedicled flap from the chest (in case of the arm) or from the opposite leg (in case of the lower member), and to cut the pedicle in from seven to ten days. The deep scar is removed at the same time, as far as possible in one mass, the surrounding muscles being then brought together to obliterate the dead space. This secures a thick fatty skin-covering for the site of the future bone operation. It is better to leave the

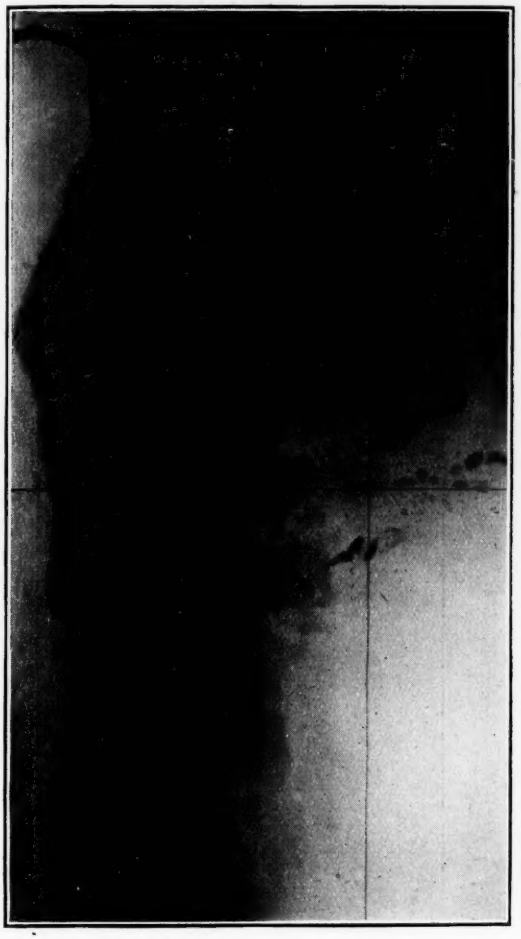


FIG. 197.—The same bone as *Fig.* 196, united over a long steel tube, which was left in place for eight weeks.

FIG. 198.—The same bone firmly united after removal of the tube.

removal of bone scar—i.e., the ends of the main fragments—until the actual reconstructive operation is to be performed; but loose bits of bone should be taken out with the fibrous scar tissue in the preliminary operation, on the two grounds that they are often the seat of latent infection, and that, being quite indolent and avascular themselves, they only tend to prevent vascularization and bone growth at the site of the reconstructed bone.

3, 4. **The Functional Conditions of the Muscles, Nerves, and Joints, including the Activity of the Circulation.**—It happens only too often that, after a long period of waiting for sinuses to heal and for latent sepsis to disappear, the general nutrition of the limb has suffered and the muscles atrophied to such an extent that a very poor prospect is offered

for bone repair. Under such circumstances it is very doubtful whether it is justifiable to operate, and the question arises whether nutrition and function can be restored before repairing the bone. Two kinds of treatment must be patiently pursued. On the one hand, the nutrition must be maintained and adhesions of the tendons and joints prevented by massage and electrical stimulation; on the other, an apparatus must be provided which enables functional exercise of the muscles to be undertaken, whilst preventing deformity. In principle, such apparatus consists in making a light splint casing for the limb, with joints at the natural articulations; being in reality the provision of a temporary exo-skeleton in place of the missing endo-skeleton. When the muscles have recovered sufficient strength under this treatment to move the limb, and when the blue, cold member has become warm

FIG. 199.—Femur of *Case* 60 three months after accident.

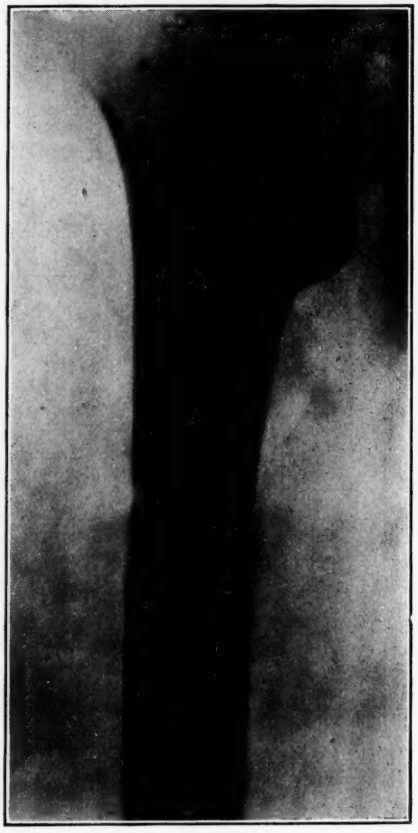


FIG. 200.—Same bone united over a 6-inch by ½-inch ivory peg. The wound healed and the fracture united.

and of a natural colour, then the bone repair may be done with good prospect of success. There is a great temptation to think that the bad nutrition and loss of function is best treated by first restoring the bone; and as I have myself yielded to this temptation, I feel it the more incumbent upon me to state clearly that it should be resisted. In general terms, the longer the period of delay and the greater trouble taken preparatory to reconstruction of the bone, the greater is the chance of success.

5. **Aseptic Technique.**—The general technique of aseptic surgery is so well known as to require no description here. Every proved source of infection and every reasonable suspicion should be guarded against, and this applies especially to the exclusion of the skin from contact with the operator's fingers and the instruments and ligatures. The most

convenient means of carrying this out is by placing the limb in stockingette, the incisions being made through this material, the edges of which are then fastened to the skin by Michel's clips.

There are two procedures commonly recommended for bone surgery which appear to me to have no sufficient justification, but to be open to grave drawbacks. One of these is the dependence on forcipressure alone for hæmostasis. I think it is far better to ligate every bleeding point with fine catgut, for there is nothing more prejudicial to healing than the formation of a hæmatoma. The other is the dictum that the gloved fingers should not be put into the wound. If the hands are clothed with rubber and cotton gloves, I see no reason to doubt the sterility of these any more than that of the instruments or swabs. Moreover, complicated joinery cannot be well done without the help of the fingers. Accurate fitting and firm fixation are the two watchwords of operative bone repair, and for these fingers are necessary.

6. **Immobilization.**—The freshly-united bone must be kept without disturbing strain until firm union has occurred. About this there can be no doubt; the only question which has to be considered is how this immobility is best secured in such a way as to interfere as little as possible with the circulation of the part and attention to the wound. If the bone repair has been done in a solid manner, then the actual fixation will be secured by this. On the other hand, if the parts, whether bone ends or bone grafts, have only been tied with soft ligatures, then reliance must be placed upon plaster-of Paris dressings. The application of these two methods of fixation will become apparent when the special operations have been considered.

IV. OPERATIONS FOR THE TREATMENT OF UNUNITED FRACTURES.

These may be divided into the following categories: (1) *Plating;* (2) *Step-cut operations;* (3) *Intramedullary pegs;* (4) *Special methods;* (5) *Bone grafting.*

1. **Plating.**—The usual operation of plating a fracture, practised upon a recent closed aseptic case, has certain drawbacks which I have dealt with elsewhere. These are briefly: (*a*) That the screws, holding only by a friction grip, are easily displaced and loosened by rarefication of bone. (*b*) That the screws, being all in one line, afford very inefficient mechanical fixation. (*c*) That if any tendency to displacement of the fracture persists, the plate becomes loosened from one fragment and allows angulation to occur. (*d*) That, in the case of a transverse fracture, a plate does not press the raw bone surfaces together, but on the contrary holds them apart.

All of these objections, which apply to recent clean fractures, are greatly increased in the case of old ununited and unhealthy bones. In the latter, fixation needs to be more secure and lasting, because natural union is so much slower and the rarefied or sclerotic bone affords a worse hold for screws than does a healthy one. To some extent the drawbacks may be overcome by using curved plates fixed by two rows of converging screws, by the use of bolts or pins which transfix the whole thickness of the bone, and by employing special plate clips which will be presently described. But even with these improvements, plating does not bring about close contact of bone surfaces, nor does it stimulate osteogenesis, but rather retards it. In the treatment of ununited fractures, therefore, plating alone must always be regarded as uncertain and unsatisfactory, and it should be reserved for special cases, or merely used as an internal splint for fixing the bone which has been united by some other method When, however, a plate is used for an ununited fracture, it is very important to fix it in such a way that it cannot become loose.

In easily accessible bones, e.g., the humerus, forearm, and tibia, and in the lower end of the femur, much the most efficient method of fixing a plate is by the use of split-pins or bolts and nuts which transfix the whole thickness of the bone. Split-pins $\frac{3}{32}$ or $\frac{1}{8}$ in. thick are cheap, easily obtained, and easily manipulated in a situation—e.g., the forearm—where both sides of the bone are accessible. The bolts I use are $\frac{1}{8}$ in. thick, and made of soft iron, so that the spare end can easily be cut off. In order to overcome the difficulty of pushing the bolt through from the deep side of the bone, I have devised a simple apparatus

whereby a nut is fixed on to the deep end of the bolt and then the latter is fixed by a second nut on the surface of the plate. *Fig.* 177 shows a fractured femur fixed by a bolted plate.

In most of the gunshot fractures in which bolted plates were used, the latter had ultimately to be removed on account of sinus formation ; but in all except one case they had remained in place long enough to secure firm union in a good line The following is a short summary of the nine cases in the present series in which plating was used.

Case 7.—Radius. Gunshot wound. Curved ivory plate fixed by ivory nails. Completely successful. Plate permanently left.

Case 29.—Humerus. Aluminium plate fixed by transfixing bolts to support a step-cut operation. Plate and bolts had to be removed because of suppuration, and the operation was a failure. Suppuration and failure were due to the operation being done only three weeks after the wound had healed

Case 36.—Humerus. Plate bolted on to support a step-cut union. Complete success. Plate and bolts left *in situ* (*Figs.* 180, 181).

Case 37.—Humerus. Plate and bolts to support step-cut operation. Plate removed after three months. Firm bony union. Successful result.

Case 45.—Middle of femur. Bolted plate. Excellent anatomical result. Legs the same length. Plate removed after six months. Great wasting of muscles. Limited movements of knee, and poor function.

Case 47.—Middle of femur. Bolted plate. Rapid recovery. Discharged with excellent function and perfect anatomical position. Six months after discharge developed an abscess in thigh and the plate had to be removed (*Fig.* 177).

Case 50.—Civil case. Man, age 50, with non-union in middle of femur and 4 in. shortening. After preliminary weight extension, the fracture was fixed by double bolted plate. The operation was very difficult, and he died two days later from shock. Post-mortem showed a fatty heart.

Case 51.—Middle of femur. Bolted plate. Sinuses developed before the wound was healed. The unhealthy bone became actually fragmented further at the points where it was transfixed by the bolts. Plate and bolts removed after four months, and union ultimately occurred.

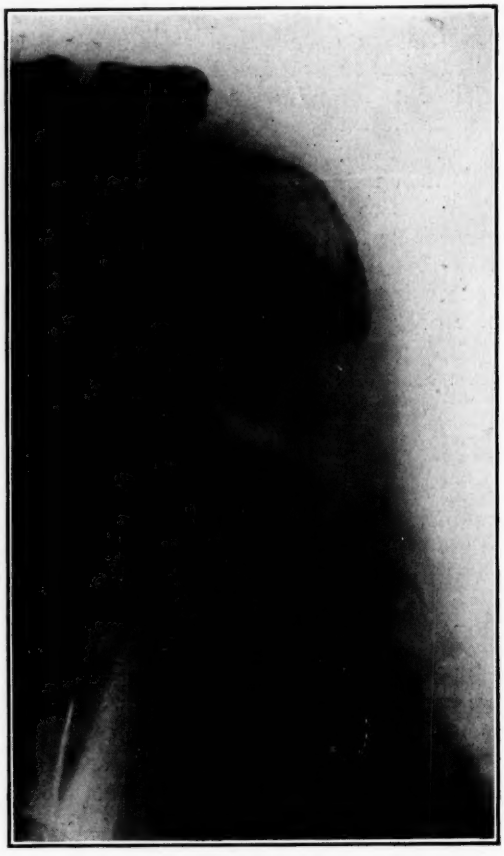


FIG. 201.—Humerus in *Case* 31; the neck of the bone has been lost.

Case 54.—Fracture of the lower end of femur, in which the distal fragment was tilted backwards. Double bolted plates were applied before the wounds were healed. Gangrene of the leg. Amputation. Tetanus. Recovery (*vide supra*).

In considering this list of nine patients, with one death, one amputation, one complete failure, one doubtful success, and only five good results, it must be borne in mind that the cases concerned were selected bad cases. It demonstrates that the mere mechanical fixation of an unhealthy bone to a plate will not secure natural union. I have learned that it is wiser to be content in some cases with less perfect mechanical fixation, in order to simplify the operation and to have less exposure of the soft parts. This can be attained in the case of the femur either by using a curved plate with two rows of screws engaging the shaft in different radii, or by the use of the clips shown in *Fig.* 179. An ordinary stout Lane plate is applied to the outer aspect of the femur with four screws. A clip is then

placed on its upper and lower end, and fixed by two screws to each, these screws entering the bone at right angles to one another. This will prevent either end of the plate from being pulled away from the bone by the tension of the adductor muscles.

2. The Step-cut Operation.—In the case of the humerus or both forearm bones, this is the best operation for ununited fracture, provided that there has not been much loss of bone or atrophy of the bone ends. It involves an ultimate shortening of the bone to the extent of about $\frac{3}{4}$ in. to 1 in.

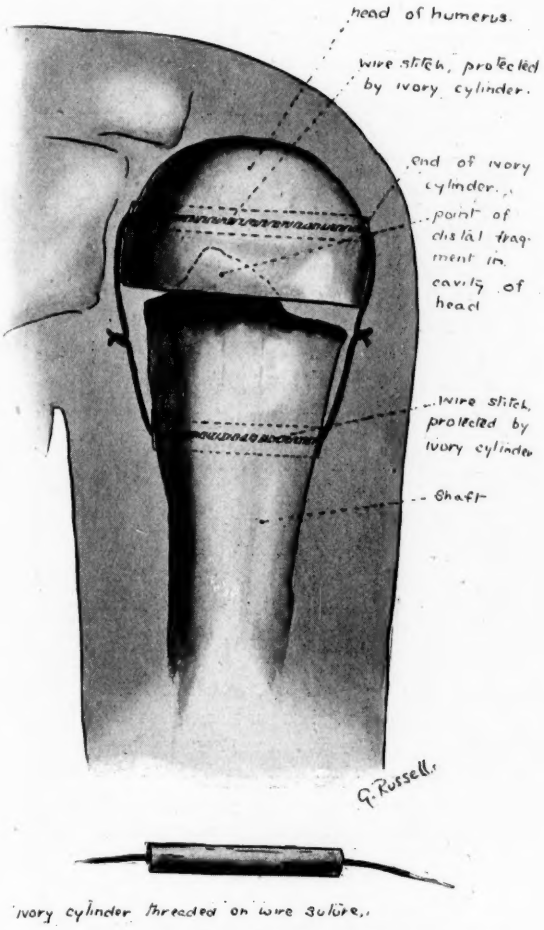

head of humerus.
wire stitch, protected by ivory cylinder.
end of ivory cylinder.
point of distal fragment in cavity of head
wire stitch, protected by ivory cylinder
shaft
G. Russell.
ivory cylinder threaded on wire suture.

FIG. 202.—Diagram of operation in *Case* 31. The wire sutures are protected from cutting out of the soft bone by being encased in ivory tubes. Successful result.

It is so simple as scarcely to require any description beyond that conveyed by the illustrations (*Figs.* 182 to 188). The bone in question is exposed, all intermediate scar tissue is removed, and the fragments are cut off square. Half the thickness of each fragment is now cut out from opposite sides in the shape of a step about $\frac{3}{4}$ in. long. The socket in each bone end is then shaped with a square file, so as to fit the other accurately. Having been fitted, the bone is held by a clamp forceps, two $\frac{1}{8}$-in. holes are drilled through both flanges in slightly different directions, and the ends are fixed by split-pins or bolts. One case is so instructive in relation to operative bone repair that I will relate it here.

Case 26.—Lieut. C. sustained a simple fracture of both bones of the forearm, March 21, 1917, by falling with his horse (*Fig.* 182). On March 23 both bones were plated in a Devonport hospital, and, as judged by *x* rays and the perfect healing of the wound (*Fig.* 183), it could not have been better done. It was immobilized for six weeks, and then the splints daily taken off for massage for a further six weeks, when recovery was regarded as complete. Slowly, however, the forearm began to bend, until by Nov. 21, eight months after the accident, he had a well-marked false joint, and came to the Bristol Orthopædic Centre for treatment. At this period the *x* rays showed (*Fig.* 184) that each plate had become loose from one bone end, by the pulling out of the screws and loosening of their sockets. A double step-cut operation was done, each bone being united by two bolts. The wound healed well, and by March 3, 1918, his arm had become so strong that he was able to return to ordinary military duty (*Fig.* 185).

It will be noted in this case that though the plates were very perfectly applied within three days of the accident, yet they did not press the raw bone surfaces together, but rather held them apart. Each bone fragment, therefore, healed without throwing out callus. When the splints were removed the bones were only held by plates and screws, and the latter quickly became pulled out from one end of each plate owing to the absorption of their sockets. This is a plain fact to be seen in the skiagram, and not a matter of conjecture. It cannot be attributed to sepsis or faulty technique, because the wound healed well and never showed any sign of irritation. On the other hand, the step-cut operation, by exposing and adapting fresh-cut bone surfaces and then closely pressing these into apposition, conformed to the ordinary principles of the suture of wounds, and resulted in strong natural union.

The step-cut operation is not suitable for leg bones, because it involves a shortening of the limb, which is a matter of only secondary importance in the arm. It is not applicable for one forearm bone the fellow of which is intact. And lastly, it requires for success that the ends of main fragments which are fitted together shall be strong and healthy, subject neither to atrophy nor to that type of sclerosis which really converts the bone into scar tissue. These latter limitations are so important that I will illustrate them by reference to three cases.

Case 27.—An ununited fracture of both radius and ulna, resulting from a gunshot wound. *X* rays showed there were several small bits of bone at the seat of fracture in each case.

Reflection ought to have led to the conclusion that if these bones had been healthy, union would have occurred; but this reflection was made too late. A step-cut operation was done at the same time that the bits of bone were removed, and the consequence was that suppuration occurred. If the fragments had been removed at a preliminary operation, spontaneous union would have probably resulted, and if not, then the step-cut operation done later would have succeeded.

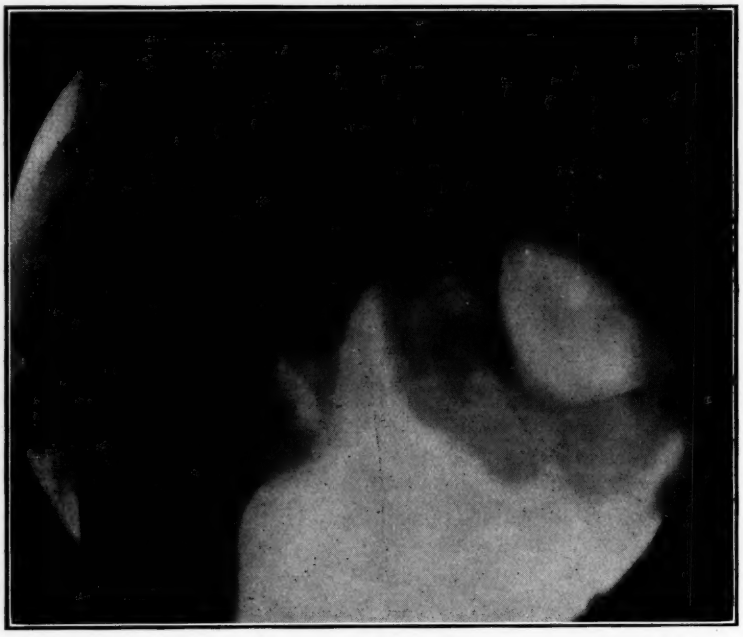


FIG. 203.—Fracture of neck of femur, which had been ununited for five months, now fixed by a tibial bone peg.

Case 33.—A case of ununited humerus with much sepsis and loss of bone, associated with complete musculospiral paralysis. Here no mistake was made in operating too soon; the patient was kept for nearly twelve months, and several preliminary operations were done for the cure of sepsis and the removal of scar tissue. At the operation a tongue of bone was found projecting downwards from the proximal fragment, and this was fitted into the lower part of the shaft and there fixed by two bolts (*Fig.* 190). At first he did well, and was so delighted at the new experience of solidity in his arm that he used it too freely. Re-fracture took place (*Fig.* 191), which is seen to be due to the tongue from the upper fragment having broken off. Disheartened by this, he asked for transfer to a hospital near his home, and I hear that at that institution amputation was performed.

Case 39.—This is almost similar to the above, except that the patient has no musculospiral paralysis, and he is still under my care awaiting further operation.

It is clear from the last two cases that if the integrity and soundness of the bone is in question, it is better to supplement the step-cut operation by a plate which takes off the strain from the actual bone ends. (See *Cases* 36, 37.) In the present series there are nine cases of step-cut operations, six of which have been completely successful.

3. **Intramedullary Pegs.**—*Short Pegs.*—The use of an intramedullary peg has very narrow limitations in the treatment of ununited fractures. It is only of use in the case of a perfectly clean and healthy bone, the fracture of which is recent, transverse, and uncomminuted, the cause of non-union being displacement with interposition of soft parts. The present series contains three such cases—one of the humerus (*Case* 34, *Fig.* 192) and two of the femur (*Cases* 49, 53, *Fig.* 193). In each of these a successful result was obtained, and in view of the ease and simplicity of the operation it is an ideal method.

The pegs I use are turned from ivory or bone. They are $\frac{1}{8}$ to $\frac{1}{2}$ in. thick, and from 1 to 3 in. long. Each has an outstanding ring at its centre, which prevents the peg from slipping down into the cavity of the fragment in which it is first placed. A small incision is required for this operation, merely large enough to allow each fragment to be thrust out of the wound. The marrow cavity of each is opened and drilled until firm bone is reached. The peg is slipped into one fragment, and the other is brought over it by traction and angulation. Such a short peg will not serve to maintain the alinement of the bone, and this must be secured by suitable splinting until union has taken place.

Long Intramedullary Pegs for the Femur, introduced from the Trochanter.—In fractures of the upper end of the femur just below the trochanters, there are two difficulties in treatment. First, the proximal fragment tilts forward and outward, and unless the thigh is kept in abduction and flexion, no amount of traction will secure alinement. Secondly, when this deformity has been established for some time in the presence of sepsis, great atrophy of the upper portion of bone takes place.

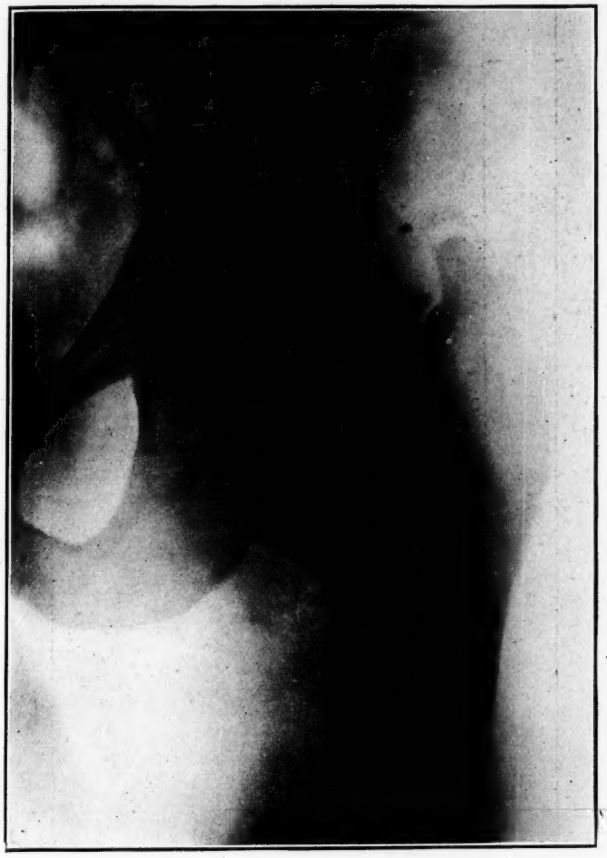


FIG. 204.—The same bone a year later, showing complete absorption of peg, and deposit of dense bone in its place. Perfect result.

In the treatment of such a fracture, whether one associated with non-union or mal-union, not only is considerable force necessary for correction of displacement, but continuous fixation by a powerful appliance of some sort is absolutely necessary in order to prevent recurrence. If this appliance is to be the external variety, it will involve many months in plaster-of-Paris; if it is a plate, then this must be fixed very differently from the manner which is generally employed. In fact, it is the study of any consecutive series of cases of this type treated by the usual Lane plate that affords the most convincing demonstration of the fallacy of the orthodox technique. Plating is nevertheless applicable if a clip or other device be employed to prevent the upper and lower ends of the plate from being separated from the bone. But in that variety of case where sepsis has long held sway and the bone fragments are very atrophic, the extensive exposure and multiple drilling necessary for plating is liable to re-awaken sepsis and to split the friable bone. It occurred to me therefore to use a long internal peg or strut, such as would render unnecessary any further fixation and would afford absolute rigidity. I have used pegs of various shapes, cylindrical, cross-sectioned, and solid rods, and I am inclined to think that the last named are the best, because they give the maximum strength, and there is an avoidance of hollows or crevices which form dead spaces. The technique of its introduction is as follows.

The limb is subjected to transfixion extension for several days before operation. (If the method is used for mal-union and not for non-union, the junction must be divided

by osteotomy before extension is applied.) Then, when overlapping and angulation have been corrected, the operation is performed. The seat of fracture is exposed by an external incision, and each fragment is refreshed and drilled by a ½-in. drill. It will be noticed that after piercing the conical end of the bone, the drill runs into the marrow cavity with the greatest ease, merely displacing a little fatty tissue. After preparing at least three or four inches of the distal fragment, the proximal one is drilled by a special drill 12 in. long. This is driven right up through the great trochanter, the tip of which is exactly in a line

FIG. 205.—Femur from *Case* 55, seven months after injury. There was remarkable comminution, but in spite of the abundant metallic débris there was no sepsis, and the wound of entry was never discovered. There was union of the small fragments with the lower end of the shaft, but non-union between this mass and the proximal fragment, which was tilted forwards.

FIG. 206.—The same bone after the use of a long fibula graft. Photo taken one month after operation. Five months later he was able to walk with crutches and work a treadle fret-saw machine.

with the axis of the femur. The tip of the drill is made to emerge against the skin of the buttock, and then cut down upon. The drill is removed, and the peg (6 to 9 in. long) is then pushed up the proximal fragment until its upper end emerges from the buttock wound and its lower is left projecting about half an inch from the bone end. The two fragments are now brought into apposition and into line, and the peg is hammered down until it engages the lower fragment by several inches. The length of the peg ought first to be determined by the position of the fracture, so that when it is in position, with at

least three inches in the distal fragment, its upper end shall remain projecting from the top of the great trochanter. This is to allow for its removal at any time if necessary.

The present series contains four instances of the use of this method (*Cases* 57, 58, 59, 60), and it must be admitted that it does not show a very favourable record.

Case 57.—The first case treated by this method, and completely successful (*Figs.* 196, 197, 198). The patient was operated upon in February, 1918, and had the peg removed eight weeks later on account of pain with a rise of temperature. He had then and has now (August) perfectly firm union in good line, and is walking on crutches; but he still has two sinuses, and the case is open to the suggestion that a septic process is still present in the interior of the femur.

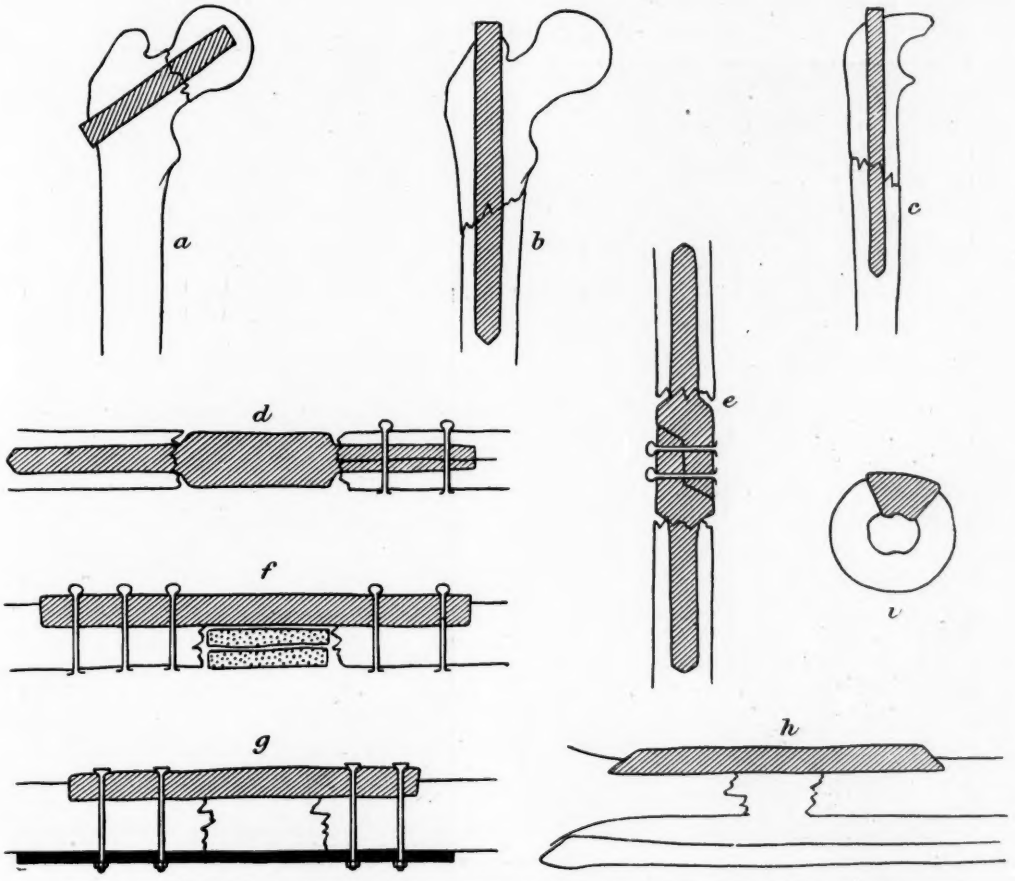


FIG. 207.—Showing methods of fixing and fitting a graft: (*a*) Graft driven into trochanter, neck, and head of femur; (*b*) Graft driven into medulla of upper third of femur from trochanter; (*c*) Graft driven into medulla of proximal part of ulna from olecranon; (*d*) Graft tightly fitted into both fragments of a fracture. At one end the shaft has been split for its reception, and then pinned together; (*e*) Graft tightly fitted into both fragments of a fracture. The graft has been cut by a fret-saw in a Z manner and pinned together afterwards; (*f*) Graft fitted as a cortical strut and fixed by pins. The fragments marked by dots have been cut from the shaft and used to fill up the gap between the main ends of the bone; (*g*) Graft fitted as a cortical strut and bolted to a plate on the opposite side of the bone; (*h*) Inlay graft fitted and fixed without metallic sutures; (*i*) Section of the inlay graft, showing its wedge shape.

Case 58.—Still has the steel strut in the femur, but there is a septic discharge from the original wound (*Figs.* 194, 195).

Case 59.—Never did well. The patient had a big scar right down to the bone, and this broke down badly in spite of plastic suturing. The peg was removed after four weeks, and later the leg was amputated at his own wish. Both these cases (58 and 59) were instances of non-union and sepsis more than twelve months after injury, and it is open to question whether any method would have been more successful.

Case 60.—Altogether exceptional, I think, but the result was so tragic that I do not feel justified in trying to explain it away or in suppressing it. It was a simple fracture with non-

union of three months' standing. I used a peg made of ivory, 6 in. long by ½ in. thick (*Figs.* 199, 200), and the result was apparently quite perfect. But eight weeks later, when the wound had healed, the patient developed influenza, which was then very prevalent in the hospital. His thigh swelled up and became very painful. The incision, being reopened, revealed much blood-clot and some pus, and he died two days later of septicæmia. The specimen recovered post mortem shows apparently perfect union of the bone.

I have seen one other case comparable to this which is worth recording. It concerns the patient of a colleague, who had plated a simple fracture of the tibia. This had healed well, and patient had been discharged to an auxiliary hospital, where he contracted influenza two months later. When he had got over this, the leg was swollen and painful, and he was re-admitted to our hospital. There it was found that he had an abscess at the site of the plating operation, and also pyæmic infection of both knee- and ankle-joints of the same limb. The plate was removed and the joints were drained, and he is making a good recovery.

FIG. 208.—Radius from *Case* 2, with characteristic displacement.

FIG. 209.—Same case after operation by tibial graft. It failed, and illustrates well the causes of failure. There is insufficient contact between the graft and its bone bed, and what contact there is concerns unhealthy atrophied bone.

However, having quite honestly stated the facts, I may go on to express my own opinion that this method of introducing a long internal peg into the femur from the trochanter is one of some value in special cases, and the unfortunate occurrence of an exceptional sequel would not deter me from employing it on another occasion.

4. **Special Methods of Operation of Occasional Value.**—In certain cases no classical method of bone repair can be adopted, and special devices may be employed. Such are illustrated by four cases of the present series.

Case 31.—Loss of bone just below the head of the humerus (*Figs.* 201, 202). After very long preliminary treatment and the removal of sequestra, the wound healed. Then the following operation was performed. The seat of fracture was exposed, and the lower fragment, shaped in

a conical fashion, was made to fit into a cavity in the head of the humerus. There was no room for any kind of plating, and a simple wire suture would certainly have cut out. Each fragment was drilled from side to side by a $\frac{5}{16}$-in. drill, and into each hole was passed an ivory tube carrying a $\frac{1}{16}$-in. iron wire. The ends of the wire were twisted together in the manner shown, after the fragments had been pressed into position. Unfortunately the ends of the wire were cut too short at one side, and here eventually the junction gave way; but nevertheless firm and good union took place, and the man has now quite a useful arm.

Case 25.—Loss of substance in the radius, associated with a gap in the flexor muscles over that bone. In this case I removed a piece of the ulna of sufficient length to allow of suture of the muscles, and the ends of the radius came together. The ulna was joined by a step-cut operation; but although the muscles have united well, and are functioning, the bone has not united; and if this continues for six months, I shall perform a bone-grafting union.

FIG. 210.—Ulna from *Case* 15, treated by a naked tibial graft fixed by encircling wire. The gap between the bone ends has been filled by the bits cut out for reception of the graft. Complete success.

FIG. 211.—Humerus from *Case* 28 after the removal of the bone graft. Illustrates the stimulation of new bone formation by the graft. Firm union ultimately resulted.

This type of operation, consisting in the removal of a segment of one bone in order to allow the falling together of its fellow, has, I think, a definite scope which is more important than is represented by the single case mentioned. It is applicable to certain fractures of the forearm and of the tibia. In the forearm, I should reserve it for those cases with a gap in the muscles as well as in the bone; because if the former are intact, I think that bone grafting, after making good the scar, is the best treatment. In the case of a tibia with a small gap between the fragments, it is a good operation, because division of the fibula will allow the tibia to come together with very little shortening (i.e., provided the gap is small), and this is a short and easy procedure compared with bone grafting.

Cases 30 and 40.—These are instances of the loss of the lower part of the humerus in arms which were much scarred and had been very septic. I divided the ulna at the junction of its middle and lower third, separated the proximal portion from its muscles, and turned it upwards, driving its lower end into the proximal fragment of the humerus. In one case this failed, and in the other it succeeded after partial exfoliation of the reversed ulna, so that I do not feel that the method has much to recommend it.

5. **Bone Grafting.**—To this method we shall devote a separate section.

V. BONE GRAFTING.

The introduction of a living autogenous bone graft is the main resource for the treatment of ununited fractures, and especially for those in which there has been definite loss of substance. Unfortunately, however, in the case of gunshot injuries there exist certain

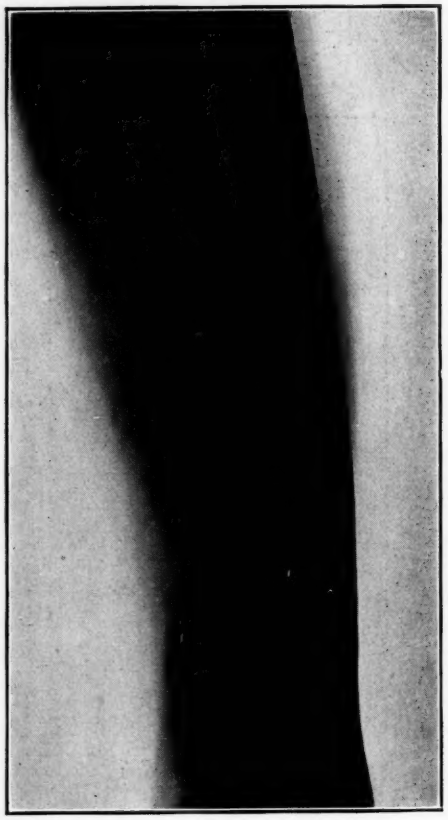


FIG. 212.—Radius from *Case* 8, before operation. There was displacement and non-union.

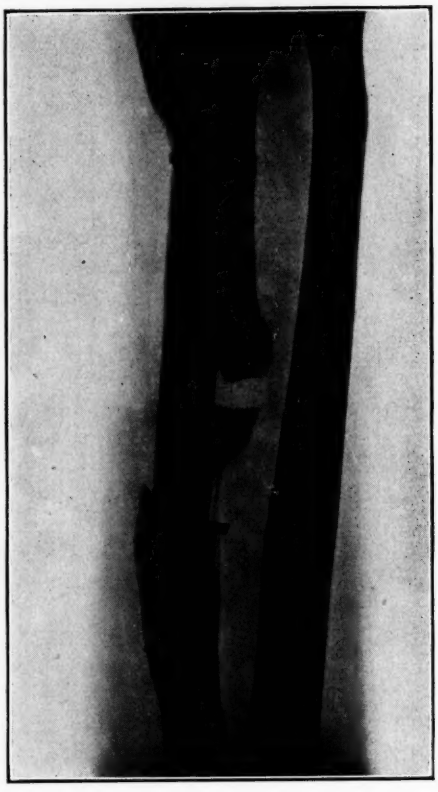


FIG. 213.—The same case after operation by tibial graft. The graft is fixed to each fragment by split-pins.

drawbacks and difficulties which make it much more difficult of success than when it is applied for the replacement of bone lost by disease—e.g., a tumour or tuberculosis. These, which have already been alluded to, are the existence of latent sepsis and the presence of extensive scars of skin, muscle, and bone.

I have recently (BRITISH JOURNAL OF SURGERY, Oct., 1917) summarized the historical account of bone grafting, and dealt fully with experimental evidence in relation to the subject, and I therefore confine myself in the present paper to clinical conditions, with special emphasis on this point, that the cardinal factors of latent sepsis, scar tissue, and deformities are features of the clinical problem not represented in experimental work.

Vital Conditions.—These must be considered in relation to the bed and the graft. The essential condition to be obtained in the bed is the removal of scar tissue, whether cutaneous, fibrous, or osseous. Ragged bone ends must be removed, and no dependence placed upon them for osteogenesis or union.

The necessary vital conditions of the graft are more readily obtained, because this will always be taken from a healthy bone.

That a living autogenous graft continues to live in its new position when joined to living bone is no longer a matter of theory or microscopic investigation. It is proved by many facts, the most convincing of which is, that when a graft becomes fractured, it produces callus just as does a living bone. This has been shown by many human cases and also by animal experiments

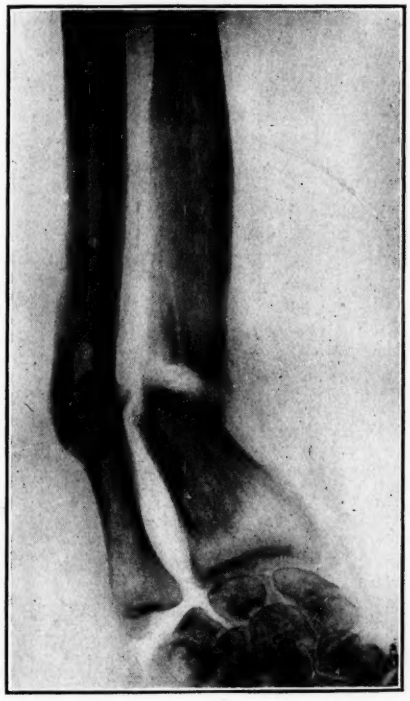


FIG. 214.—Fractured forearm bones from *Case* 6. There is mal-union of the ulna and non-union of the radius.

FIG. 215.—The same bones after operation. The ulna has been rectified by a step-cut operation, and the radius united by a long tibial graft, both fixations being effected by split-pins. Complete success.

That *the periosteum* is not an essential element in the graft is proved by the fact that in many cases a naked graft heals in position and becomes united to its bed (*Cases* 11, 15, *Fig.* 210). The best example of this is in the living tibial peg driven into the neck of a fractured femur. Nevertheless, the preservation of the periosteum is very desirable in all cases except those where the graft is entirely intramedullary. There are two reasons for this. The most important is that the periosteum is the medium through which new blood-vessels most readily make connection between the graft and its surroundings. It is the natural vascular envelope of the bone, which is ready to take up a new blood-supply. Secondly, removal of the periosteum involves the removal of the very important superficial layers of osteoblasts, from which more bone growth takes place than anywhere else in the graft. Further, the preservation of the periosteum affords a ready method of suturing the graft in its place in those methods where no metallic sutures are employed.

The rôle of the periosteum is remarkably demonstrated by the comparison of three types of operation :—

1. Where a naked graft is used, increase in thickness of the graft, even after long survival, is very slow. Whenever sepsis supervenes, the graft becomes entirely exfoliated without depositing any new bone (*Cases* 1, 2, 3, 10, 11, 16, 28, 29).

2. Where periosteal flaps with a thin layer of bone are turned down to bridge the gap, no new bone is deposited, and failure results. This shows that periosteum, even when retaining its attachment, will not deposit new bone in an adult (*Case* 20).

3. Where a graft covered on one surface by its own periosteum is used, its behaviour is different from either of the above groups. Increase in thickness occurs

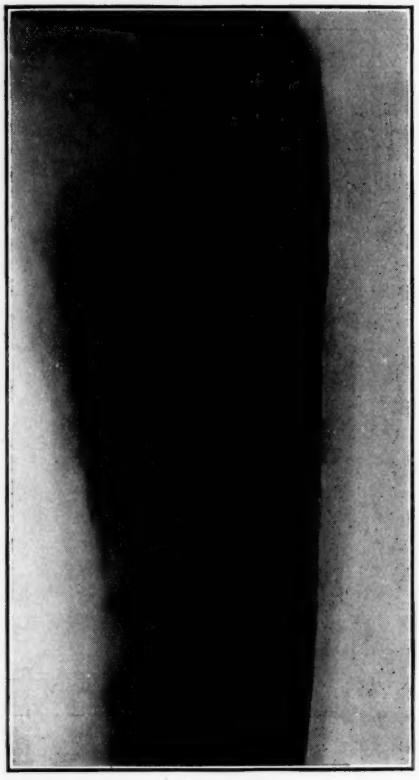


FIG. 216.—Fracture of the radius from *Case* 12.

FIG. 217.—The same bone after union by a graft. The upper end of the graft has been driven into the marrow cavity of the proximal fragment, and the lower end placed in the cavity of the distal fragment after splitting the bone. United by two pins. Complete success.

in all cases within a few months. In those cases where secondary sepsis supervenes, there is an abundant deposit of new bone between the periosteum and the graft. The solid portion of the graft may be exfoliated, but a mass of new bone is left behind of larger bulk than that originally used. In *Case* 5, *Fig.* 220, for example, a periosteum-covered graft was bolted to the radius, to an aluminium plate on the opposite surface. Four months later a sinus persisted. There was massive new bone formation, and on removal of the plate and bolts ready healing took place, the gap being more than filled by new bone. In *Case* 9, two grafts were bolted to opposite surfaces of the incomplete radius, each having a periosteal covering on its outer side. A sinus developed, and persisted. Five months later the wound was opened up. One graft had undergone a central necrosis, the rest being incorporated with the living

tissues. The other graft had almost entirely necrosed in its solid portion, but there was a mass of new bone forming an involucrum on its surface. There was firm and solid new bone filling the gap, although a large amount of the dense bone put in was lost.

Thus we have three facts: (1) Naked grafts form new bone very slowly and scantily; (2) Periosteal flaps in adults form no new bone at all; (3) Bulky grafts covered by periosteum are capable of depositing thick new bone in the form of an involucrum. From these facts it may be inferred that the osteoblasts necessary for new bone formation are contained in the dense bone, but that the protecting and vascularizing matrix of the periosteum is necessary for their activity.

The best source of the graft has been much discussed, but for repair of the long bones I think that the crest or internal surface of the tibia holds most advantages. From this bone the greatest length and strength can be obtained with the minimum exposure or damage to soft parts. It is well provided with thick periosteum, and is readily accessible for accurate sawing. From the crest may be obtained a strong bone $\frac{3}{4}$ in. square in section, and from the surface a long thick plate $1\frac{1}{2}$ in. wide and $\frac{3}{8}$ in. thick. The only serious objection which can be urged against the use of the tibia is the fact that fracture sometimes occurs in it after the removal of a thick graft. This has happened in two of my cases, but in each it was only a small fissured fracture without displacement, and I do not regard it as of serious import ance. The fibula has some points to recommend it. These are, that it presents a rod-shaped bone which requires no cutting, and that it is not an essential feature in the skeleton; but it is very variable in its shape and size, and it is difficult to clear it of muscle without stripping it of its periosteum. With a proper motor saw a good graft can be cut from the tibia much more quickly than from the fibula, in the case of a muscular leg.

In determining the size of the graft two points must be borne in mind. First, that no new bone of any mechanical importance can be expected to arise from it for many months, and that it must therefore be cut large enough to fill the gap it has to replace as far as possible. Secondly, that as the graft ought to have contact with a wide surface of bone bed on each side, it must be cut of sufficient length to secure this. The ideal length is not less than three times that of the gap. For example, if there is a gap of two inches between the main fragments after their unhealthy ends have been cut off, then the graft ought to be six inches long.

A further vital condition to be considered is that relating to the contact between the graft and its bed. Rapid and sound union will depend upon broad and accurate contact efficiently maintained, and it must be a main object of the technique to secure such contact. Just as bone gaps are filled very slowly or not at all, so any spaces between the bone graft and its bed offer obstacles to bony union. Next to the importance of eliminating latent sepsis and scar tissue, nothing has impressed me more than the dependence of success in bone grafting upon this accurate contact. A reference to *Figs.* 208, 209, from one of my earlier cases, will at once illustrate the type of union which is doomed to failure.

Mechanical Fixation.—The success of all plastic surgery depends largely upon accurate suturing. Bone, being a tissue of slow growth and slow repair, requires more firm and lasting sutures than the soft tissues. There are three methods used for the fixation of a graft; (1) *Suture by ordinary absorbable ligatures;* (2) *Fitting by accurate joinery;* (3) *Fixation by means of metal screws, pins, wires, or plates.*

1. The first method, that of ordinary suture—i.e., of the periosteum of the graft to that of its bed—is only suitable for situations where there is no tendency to movement or displacement, e.g., in the repair of defects in the cranium; here, indeed, no sutures are really necessary. In the long bones, catgut or animal-tendon suture cannot be regarded as a serious method of fixation except for the attachment of the periosteum. If any strain has to be borne by ligatures in the fixation of a graft, then my own choice would be of some metal suture, e.g., a bolt or a pin; but

failing such, I think it is better to use a piece of the patient's own fascia or tendon than to place any reliance upon catgut or animal tendons. In the leg, strands of the fascia lata, and in the arm a piece of the palmaris longus tendon, are far better suture materials than pieces of sheep's intestine or kangaroo tail.

2. The method of fixation always to be aimed at is that of fitting the graft into a slot or cavity in the bed in such a way as to require no suture at all. When this can be well done, the method in my experience never fails, provided latent sepsis has been eliminated and scar tissue removed. The simplest type of this fixation is seen in the use of a square tibial peg driven into the cancellous tissue of the femoral neck

FIG. 218.—Forearm from *Case* 22. The ulna had been lost in childhood from osteomyelitis. Patient had nevertheless served as a soldier until he dislocated the head of the radius.

for fracture of that bone. I have never had a failure with this operation, and *Cases* 46, 48, and 52 are good examples. *Case* 46 has been under observation for more than a year (*Figs.* 203, 204). Although he was discharged from the army by a medical board, who evidently were sceptical about reconstructive bone surgery, he has now such perfect function in walking and running that it is impossible to detect which is the injured leg.

In the same way, the living intramedullary peg can be used as a graft for the repair of fractures in certain situations, viz., the upper or proximal third of the femur or ulna. That is to say, in both these situations a peg can be firmly driven into the

shaft of the bone so that graft and bed are firmly contacted in the whole length of the former. It must be carefully noted that this is a very different procedure from putting a living intramedullary peg into the site of a fracture, introducing it into one broken end and then bringing the other over it (as in the use of the short pegs described above). This latter procedure is by clinical and experimental evidence likely to fail, because the peg is so short and the fitting so loose. In the firmly-fitted living peg the shaft of the bone should be drilled much smaller than the peg, and the peg should not be round but angular in section. For example, in the femur the shaft is hollowed by a $\frac{3}{8}$-in. drill, which leaves a margin of at least $\frac{1}{8}$ in. of fairly

FIG. 219.—The same arm after insertion of a long tibial graft fixed above by two split-pins.

soft bone all round the cavity. A square peg is cut from the tibia, 6 in. long and $\frac{5}{8}$ in. thick, and then filed down so as to pass through a $\frac{1}{2}$-in. hole. It then has a roughly octagonal section, and can be hammered into the $\frac{3}{8}$-in. hole so as to hold very firmly, and 3 in. will lie on each side of the line of fracture.

There are two other methods by which a graft can be firmly fitted as an intramedullary peg, and these are specially suited for cases where there has been a loss of substance (*Fig.* 207). Suppose that the gap to be filled is 2 in. after removal of unhealthy bone from the ends of the fragments; suppose that it is the radius to be repaired, having an outside diameter of half an inch and an inside cavity of a quarter

of an inch. The graft is cut square and of 6 in. length. Each end is shaped with a file for 2 inches, until it fits tightly the holes drilled in the fragments. Into one fragment the graft is driven (temporarily wrapping the bone round with several turns of wire to prevent splitting). The other fragment is cut for 2½ in. with a fret-saw, and the two halves are prized apart so as to take the spindle at the other end of the graft. Then this split end and the contained graft are sutured through two holes by suture or split-pins (*Fig.* 216, 217). In the alternative method, which is to be used if one fragment of the bed cannot be split as above described, the graft, having been shaped so as to fit at each end, is itself cut into two portions by a Z-shaped incision. Each half is hammered into place, and then the graft fitted together and sutured or pinned.

FIG. 220.—Radius from *Case* 5.

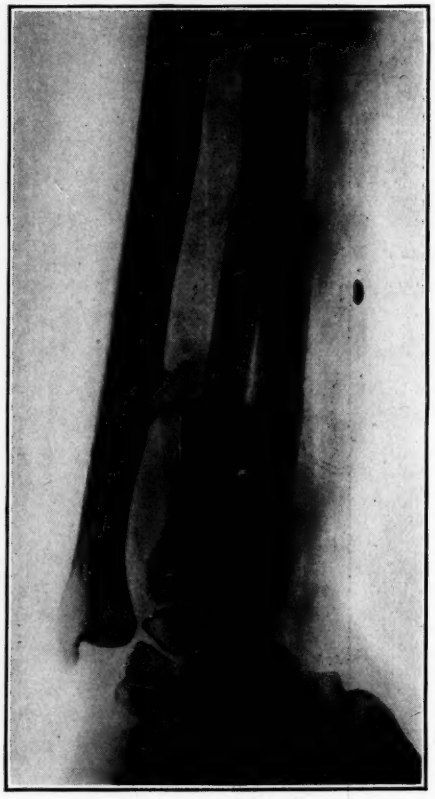


FIG. 221.—The same after operation. The bone has been united between a tibial graft and an aluminium plate by four bolts.

The inlay cortical graft, which has been used and popularized by Albee, is a superficial graft, laid down in a slot cut for it in the cortex of the bone to be mended. Albee uses a twin saw, but if the same twin saw be used to cut the graft and the slot into which it is to fit, then the latter will be too large by two saw thicknesses, and for strong work I think it is better to make a shelving trough, cutting each side separately with a simple saw-cut. Then the graft can be hammered down into its bed, the hollow bone having enough elasticity to open a little for its reception. The ends of the graft should be bevelled so as to underlie the ends of the slot. Thus the muscular tension will prevent the graft from slipping out (*Fig.* 224).

In some cases one end of the graft may be shaped as a peg and driven into

the marrow cavity, while the other end is recessed into a flat cut on the other fragment and there secured by pins (*Figs.* 222, 223).

3. Finally, the use of wire nails, screws, bolts, or plates as a method of fixation must be considered. And in this connection it is wise to hold a temperate and reasoned opinion which avoids impracticable extremes. The fact that wire, plates, and screws have often been unwisely used and caused trouble, is not sufficient reason to reject metallic suture when this will afford definite advantages. That there is nothing essentially hostile to a graft in the presence of metal sutures is proved by the many cases in which success has followed this method of fixation. In 13 out of 19 successful cases in the present series metal sutures were used. If it is admitted on the one hand that firm fitting without metal sutures is always the ideal method of grafting, it must, I think, also be granted that firm fixation by metal sutures is better than insecure fixation without, and I have given experimental demonstration of this. There are many cases where the graft has to be laid with some tension—i.e., the graft itself has to act as a splint securing alinement. Such a case is well illustrated by the common fracture of the radius—cf. *Case* 6, *Figs.* 214, 215. In such a case, if a strong graft is securely bolted or pinned to its bed, then it will heal well; whereas if it was merely tied in its place, it would surely allow angulation to occur, and probably the graft would be extruded.

FIG. 222.—Forearm bones from *Case* 23. There was mal-union of the radius and a large gap in the ulna.

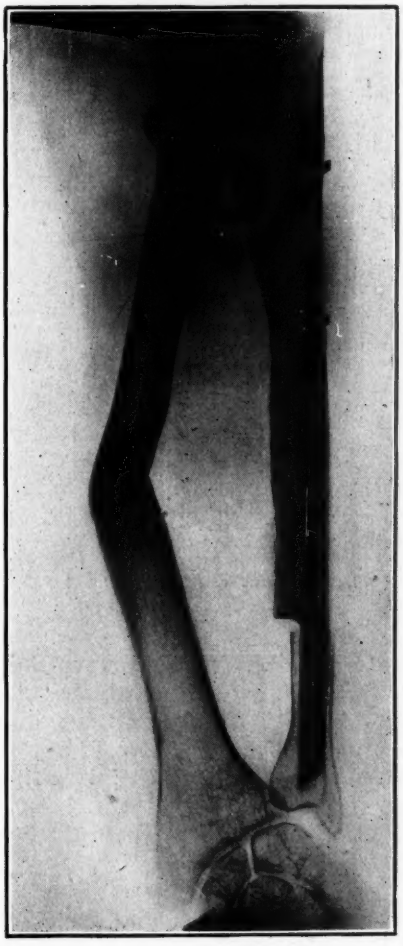


FIG. 223.—The same bones after operation. As the radius was displaced away from the ulna, it was left alone. The ulna was united by a long tibial graft, pegged into the lower fragment and united to the upper by two split-pins.

I have successfully used encircling iron wire, split-pins, bolts, and plates for the fixation of a graft, and these various methods are so well shown in the accompanying radiograms that it is hardly necessary to describe them in detail. The split-pin is, however, the method which gives me the greatest satisfaction. These pins are the ordinary cotter-pins to be bought at any ironmongers. I use them in thicknesses of $\frac{1}{16}$, $\frac{3}{32}$, and $\frac{1}{8}$ in. The bone bed and the graft are perforated by a suitable drill, the pin thrust through, and its ends are turned up and cut off and pressed home (*Figs.* 213, 219).

Another point to be borne in mind is that the use of firm metal fixation will greatly simplify after-treatment, inasmuch as much less plaster-of-Paris immobilization

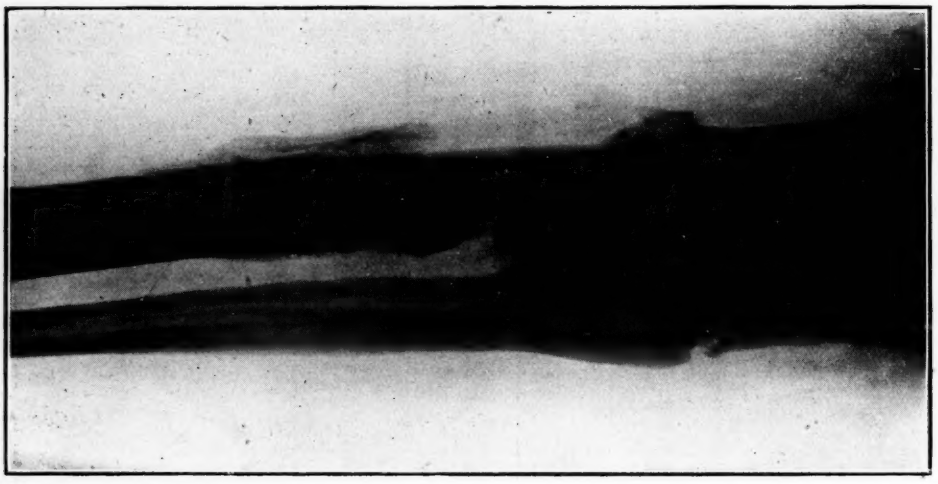


FIG. 224.—Tibia from *Case* 43. Successfully united by an inlay graft from the opposite tibia fitted without the use of metal sutures.

is then required. In the forearm bones, for example, the limb is kept on a simple splint for a few days until the smooth healing of the wound is secured; then plaster is applied for two or three weeks; and after this the man is set to light work without any splint or plaster of any kind; and I claim that in this way much more rapid restoration of function is obtained than by keeping the limb for months in plaster.

Results obtained by Bone Grafting in the Present Series.—The series contains 34 cases of autogenous bone grafting. Of these, 10 (29·4 per cent) have been failures, 5 (14·7 per cent) have been eventual successes in producing bone union after extrusion of the graft (*Fig.* 211), and 19 (55·8 per cent) have been complete successes.

The results are further analyzed in the following table:—

	Number of Cases	Failures	Partial Successes	Complete Successes
Radius	10	3	1	6
Ulna	12	4	1	7
Humerus	3	1	1	1
Tibia	4	1	2	1
Femur	5	1	—	4
Totals ..	34	10	5	19

The most important matter for consideration is that of the failures and their causes. In every one of the 15 cases where success was not complete, the cause of failure can now be traced.

In four cases (1, 2, 10, 14) the operation was performed much too early, i.e., in periods of a few days up to three weeks after healing.

In three cases (3, 17, 42) only scanty contact between the graft and its bed was secured.

In one case (13) a sliding graft was done; that is to say, sclerosed avascular bone was taken from one fragment and made to bridge the gap.

In one case (18) the patient fell on his arm and broke the graft, bursting open the wound.

In one case (29) the graft was laid in unhealthy bone which should have been removed.

In one case (56) too complicated a procedure was adopted, and the patient died of shock.

In one case (28) the humerus was not immobilized adequately, and the arm, hanging on the graft, broke the fixation.

In two cases (41 and 44) scars in front of the tibia were not sufficiently replaced by healthy tissue before grafting.

In one case (20) periosteal flaps with thin bone scales adhering to them were turned down over the gap, and produced only a shred of bone.

In contemplating these results, my feelings are those of mingled disappointment and hope—disappointment that the proportion of successes has been so small, and hope that by the experience gained one may be able in the future to avoid causes of failure which are seen to be so obvious, and therefore so possible of evasion.

In conclusion, it is my pleasant duty to thank Dr. Honeyford, Captain Moore, and Captain Wace for the indispensable help they have given me both in the operations and after-treatment of these cases.

[*Particulars of Cases on next page.*

PARTICULARS

Case and Age	Bone	Cause of Non-union	Period	Operation
1 Pte. W. W. Age 33	Radius	Gap 1½ in.	5 months non-union, 3 weeks healed	Naked tibial graft, fixed by wire.. .. .. ..
2 Cpl. C. N. Age 21	Radius	Gap 2 in.	10 months non-union, just healed	Naked tibial graft, fixed by wire (*Figs.* 208, 209) .. ..
3 Pte. J. C. Age 24	Radius	Gap 1½ in.	10 months non-union. 2 months healed	Naked tibial graft, fixed by one wire and one ivory nail at each end
4 Pte. C. S.	Radius	Gap ½ in. and displacement	12 months non-union, 5 months healed	Fibula graft, fixed by one wire and two ivory nails at each end
5 Pte. T. Q. Age 36	Radius	Gap 1 in. and displacement	6 months non-union, 4 months healed	Excision of scar. Tibial graft with periosteum supported by a metal plate (*Figs.* 220, 221). No after-splint used
6 Gnr. S. W. Age 41	Radius	Gap 2 in.	5 months non-union, 3 months healed	Preliminary scar excision 1 month before bone operation. Mal-union of ulna corrected and united by step-cut. Tibial graft with periosteum fixed at each end by two split-pins (*Figs.* 214, 215).
7 Gnr. T. S. Age 37	Radius (closed fracture)	Displacement	1 month non-union, no wound	Curved ivory plate, fixed by 6 ivory nails.. .. ..
8 Sgt. C. W. S. Age 40	Radius	Displacement	8 months non-union, 7 months healed	Attempt to use a sliding graft abandoned because of tension necessary to secure alinement. Tibial graft with periosteum fixed by 5 pins (*Figs.* 212, 213). .. .. ..
9 Pte. W. A. R. Age 20	Radius	Gap 2 in.	13 months non-union, 3 months healed	Preliminary replacement of scar tissue by skin flap from chest. Two tibial grafts with periosteum bolted together, one each side of fragments
10 Pte. J. G. Age 35	Radius	Gap 2 in.	10 months non-union, recently healed	Naked tibial graft, fixed by wire. Scar tissue was not removed
11 Pte. J. McM. Age 28	Radius	Gap 1½ in.	4 months non-union, 3 months healed	Naked tibial graft fixed by wires .. .. ..
12 L-Cpl. R. G. Age 35	Radius	Gap 1 in.	10 months non-union, 4 months healed	Preliminary operation for removal of scar and bone débris. Tibial graft with periosteum, 5 in. long, shaped as a peg at each end, driven into marrow cavity of shaft at one end and let into the other after splitting (*Figs.* 216, 217)
13 Pte. H. T. Age 27	Ulna	Displacement	12 months non-union, 3 months healed	Sliding graft. The bone was very dense and avascular, the marrow cavity being obliterated
14 Pte. G. W. Age 27	Ulna	Gap 2 in.	4 months non-union, recently healed	Sliding graft, fixed by wire .. ..
15 Pte. D. McC.	Ulna	Eburnation and plating	17 months non-union, 12 months healed	Plate and four screws which were loose removed. Multiple drilling of ends to promote vascularity. Tibial graft without periosteum fixed by wire (*Fig.* 210)
16 Cpl. G. E. Age 23	Ulna (closed fracture)	Displacement	18 months non-union, no wound	Five previous operations, wiring and plating, had been done. Sliding bone graft
17 Cpl. A. G. P. Age 25	Ulna	Displacement and gap ½ in.	11 months non-union, 3 months healed	Fibula graft, fixed by two nails and one wire to each fragment

OF CASES.

RESULT	REMARKS
Failure	Operation was done within 3 weeks of healing of wound, and the scars were not excised as a preliminary. Chronic suppuration from 7th day onwards until removal of graft after 5 months. Some new bone had formed, but not enough for union.
Failure	Operation done directly wound had healed. Whole of scar tissue sloughed. Graft removed after 3 months. Gap reduced to 1 in. but no union. There was obviously insufficient contact between the graft and its bed (*Fig.* 209).
Failure	Operation 2 months after healing. Suppuration not manifest until 10 days after operation. Graft removed after 4 months.
Success	Five months after operation, good function in hand.
Success	There was such a strong tendency to displacement of both radial fragments towards the ulna that a plate was necessary to reinforce the graft. Good strong hand-grip 8 months after operation.
Success	Five months after operation has a strong hand-grip with supple movements, including rotation of wrist. Within two months of operation he could do basket-making, wearing only a light cock-up splint.
Success	Rapid recovery of function. Discharged to military duty after 2 months.
Success	Rapid recovery of function. Discharged to Command Depôt 2 months after operation.
Success	Remarkable instance of the value of the periosteum. Four months after operation a sinus persisted. Wound opened : the dense parts of the graft were partly necrosed, but there was a heavy deposit of new bone from the superficial parts of each graft, forming a perfect union.
Partial success	Premature operation. Scars should have been excised. The scar tissue broke down, and the graft was in part extruded. Much new bone was deposited, so that weak union was established.
Success	An example of success with a naked graft without periosteum. After 2 weeks, massage begun. After 2 months, discharged for military duties.
Success	Very satisfactory result. After two weeks in plaster he wore only a light cock-up splint and was able to do basket-work. Three months after operation his arm is almost normal.
Failure	The incision healed, but the original scar broke down. This should have been excised as a preliminary. It would have been better to have taken a tibial graft, because the ulna itself had become so eburnated.
Failure	Premature operation. All the scar tissue broke down, exposing the graft.
Success	The drilling of the fragments was done to cause union, but failed in this object until the bone graft was used two months later. Firm union and good functional result.
Success	Two months later, good functional result, and patient was discharged to Command Depôt.
Partial success	Ten days after healing the wound broke down. After 4 months the graft was removed. There was some new bone and a weak union.

Continued on next page

PARTICULARS OF

CASE AND AGE	BONE	CAUSE OF NON-UNION	PERIOD	OPERATION
18 Pte. J. L. Age 23	Ulna	Gap 1½ in.	9 months non-union, 3 months healed	Long naked tibial graft, fixed by wire and ivory nails ..
19 Pte. G. A.	Ulna	Gap 1 in.	9 months non-union, 4 months healed	Sliding graft, fixed by wire .. ..
20 Pte. A. G. Age 38	Ulna	Gap 1½ in.	10 months non-union, 4 months healed	1. Scars excised as a preliminary. 2. Two flaps of periosteum 3 in. long turned down from upper fragment and sewn to lower, taking a thin layer of bone with them
21 Pte. E. C. Age 19	Ulna	Displacement	6 months non-union, 4 months healed	The ulna was overlapping, and was united by a step-cut operation. (The radius had been fractured but was united)
22 Pte. R. G. I. Age 42	Ulna	Old osteomyelitis	34 years non-union, no recent wound	The radius was dislocated, and it was this which caused the disability. Ulna replaced by a long tibial graft with its periosteum, united above to the olecranon by pins. Head of radius removed (*Figs.* 218, 219).
23 L-Cpl. F. C. Age 23	Ulna	Gap 3 in.	18 months non-union, 5 months healed	Two preliminary operations for removal of scars and sequestra. Long tibial graft with periosteum: lower end, peg-shaped, driven into distal fragment; upper end fixed by pins
24 Pte. G. J. Age 22	Ulna	Gap 2 in.	12 months non-union, 4 months healed	Operation exactly similar to last .. .. ..
25 Pte. H. C.	Ulna and radius	Gap 1 in.	6 months non-union, wounds unhealed	Ulna was shortened, and united by a step-cut. This allowed the radius to come together and the divided muscles to be sutured
26 Lt. W. A. C. Age 25	Ulna and radius	Eburnation and plating	8 months non-union, no wound	Step-cut operation for both bones; joined by bolts (*Figs.* 182, 183, 184, 185)
27 Pte. J. S. Age 35	Radius and ulna	Necrosis	—	Operation revealed a number of small bits of bone between the main fragments. These were removed, and both bones united by a step-cut
28 Sgt. R. A. Age 34	Humerus	Gap 1 in.	8 months non-union, 3 months healed	Naked tibial graft, fixed by four wires .. .. ..
29 Pte. F. B. Age 33	Humerus	Gap 1¼ in.	11 months non-union, 4 months healed	1. Naked tibial graft, fixed by four bolts. 2. After failure of graft the bone was fixed by two aluminium plates
30 Pte. T. S.	Humerus	Loss of lower third of bone	7 months non-union, 3 months healed	Ulna cut through and turned up and pegged into humerus ..
31 Pte. H. M. Age 41	Humerus	Gap 1½ in.	15 months non-union, 3 months healed	Shaft shaped as a peg and impacted into head, fixed by two wires threaded through ivory tubes (*Figs.* 201, 202)
32 L-Cpl. C. H. Age 26	Humerus	Displacement	7 months non-union, 3 months healed	Step-cut operation, united by two bolts .. .. ..
33 Pte. J. R. Age 27	Humerus	Gap 1½ in.	17 months non-union. 3 months healed	Several preliminary operations for removal of scar tissue. Step-cut operation, using a natural spur of the upper end for one step

CASES—*continued.*

RESULT	REMARKS
Failure	Twelve days after operation patient fell on his arm, fracturing the graft and breaking open the wound. Two months later graft removed.
Success	Rapid recovery of function. Discharged to civil employment after 3 months.
Failure	An instructive example of the feeble osteogenesis of periosteum. After 4 months two little lines of bone could be seen, but there was no skeletal union ; 6 months after operation a sinus formed, and both pieces of bone were extruded.
Success	Discharged for military service.
Success	So much shortening of the arm had occurred that it was impossible to replace the radial head. His arm is now fairly strong, his grip is good, and he can flex the elbow to an acute angle and fully extend it.
Success	The radius had been fractured, but had firmly united. It was angulated away from the ulna and therefore not re-fractured. No splint was worn, and rapid restoration of function took place.
Success	Discharged for civil employment.
Partial success	A part of the radius and the overlying flexor muscles had been blown away. Only by shortening of the ulna could the muscles be restored. The muscles are now acting well, but the radius has not yet united.
Success	A simple fracture, perfectly plated, but in spite of primary healing non-union occurred, the screws being loose. Good strong arm 3 months after the step-cut operation. Returned to military service.
Partial success	Suppuration occurred and was difficult to cure. After 6 months there was good union in both bones, but it it is clear that the bits of dead bone should have been removed before anything else was done.
Partial success	If the arm had been put up in plaster it would probably have succeeded. As it was, the weight of the arm pulled the graft out of place, and the latter had to be removed after 4 months. Good union occurred from callus stimulated by the graft (*Fig.* 211).
Failure	Failure in both cases was due to not going wide enough of the unhealthy wound and taking hold of good bone tissue. He is waiting for a further operation.
Failure	He had complete musculospiral paralysis, and after failure of this operation the arm was amputated.
Success	There was no room for any form of plate or graft. The only alternative would have been removal of the head of the humerus. By passing the wires through ivory tubes, the former were prevented from cutting out.
Success	There had been musculospiral weakness, which rapidly recovered after the bone operation. It must have been due to dragging on the nerve. Discharged after 3 months to military service.
Failure	It was a mistake to rely upon an end of unhealthy bone for union. It should at any rate have been reinforced by a plate. The upper step broke off, and, after discharge of patient to another hospital the arm was amputated.

Continued on next page

PARTICULARS OF

CASE AND AGE	BONE	CAUSE OF NON-UNION	PERIOD	OPERATION
34 Pte. H. G. Age 32	Humerus	Displacement	6 weeks non-union, no wound	Short ivory intramedullary peg (*Fig.* 192) .. ..
35 Sgt. J. H. Age 32	Humerus	Displacement	7 months non-union, 2 months healed	Step-cut operation .. ..
36 Sgt. G. P. Age 25	Humerus	Gap 1 in.	6 months non-union, 3 months healed	Step-cut operation, reinforced by double aluminium plates
37 Pte. J. R. Age 23	Humerus	Gap 1 in.	13 months non-union, 1 month healed	Step-cut operation, supported by two plates bolted together
38 Pte. A. B. Age 24	Humerus	Loss of lower third	7 months non-union, 3 months healed	Tibial graft driven into lower end of humerus as a peg ..
39 Sgt. F. R. Age 23	Humerus	Necrosis	12 months non-union, 3 months healed	Step-cut operation, bolted. Necrosed fragments were found in some pus
40 Pte. J. B. Age 32	Humerus	Loss of lower third	10 months non-union, 6 months healed	Ulna divided at lower third, turned up, and pegged into humerus
41 Pte. J. C. Age 25	Tibia	Gap 1½ in.	12 months non-union, 3 months healed	Graft from opposite tibia, fixed by wires .. .. ..
42 Pte. J. L. Age 22	Tibia	Gap 1 in.	2 years non-union, 6 months healed	Graft from opposite fibula bolted through the tibia to fibula of same side
43 Pte. W. S. Age 30	Tibia	Gap 1½ in.	13 months non-union, 2 months after excision of scar	Preliminary scar excision. Inlay graft from opposite tibia fitted without suture. Plaster-of-Paris for three months (*Fig.* 224)
44 Sgt. F. H. Age 30	Tibia	Gap 2 in.	8 months non-union, 3 months healed	Inlay graft from opposite tibia fixed by wires. The tibial graft was prepared six weeks before use by multiple drilling *in situ*
45 Pte. W. F. Age 20	Femur, middle	Displacement	3 months non-union, no wound	Bolted plate .. ..
46 Pte. A. C. Age 22	Femur, neck	Displacement	3 months non-union, 2½ months healed	Tibial bone peg (*Figs.* 203, 204) .. .. ..
47 Cpl. R. J. Age 24	Femur, middle	Displacement	7 months non-union, 3 months healed	Bolted plate (*Fig.* 177)
48 Pte. J. U. Age 26	Femur, neck	Displacement	12 months non-union, 10 months healed	Previous operation by a single screw, which had bent and become displaced. Tibial bone peg
49 Pte. J. H. Age 25	Femur, upper third	Displacement	3 months non-union	Short ivory peg (*Fig.* 193) .. ..
50 J. J. Age 49	Femur, middle	Displacement	10 years non-union, no wound	Double bolted plates .. ..

CASES—*continued.*

Result	Remarks
Success	Discharged to Command Depôt.
Success	Slow but good return of function.
Success	The bone had been so widely comminuted that the plates were necessary for strength. Discharged to civil employment.
Success	Operation rather premature. Plates had to be removed after 3 months because of sinus. Good bone union.
Success	The arm was put up flexed, and the end of the graft came through the skin and a small portion had to be removed. It would have been better to put the arm up in extension, so as to bury the graft in soft tissues.
Failure	Suppuration. The necrosed bone should have been removed without any further operation.
Partial success	A part of the reversed ulna was exfoliated, but the remainder healed well in its new position, and he promises to have a useful arm.
Partial success	The anterior scars broke down, and the graft was slowly exfoliated piecemeal. There was solid union of the original bone, and sound healing after 8 months.
Failure	Too elaborate an operation. There was never accurate fitting between the graft and its bed. Necrosis occurred, and eventually the leg was amputated.
Success	There was a temporary breakdown of the scar and a trifling exfoliation of the graft. Strong firm union. Discharged to civil employment.
Ultimate success	The anterior scars gave way partially in spite of having been replaced by new skin. The graft was slowly exfoliated, but when it had been entirely removed there was firm union between the original fragments and cross-union with the fibula. Discharged to civil employment, walking well.
Success	Plate removed after 4 months. Perfect union of bone, but much wasting of muscles and a rather stiff knee. Civil employment.
Success	Twelve months later he could walk and run, so that it was impossible to guess which had been the injured leg.
Success	The plate was removed 6 months later because of an abscess. The bone was firmly united and the two legs the same length.
Success	Five months later could walk well. Discharged for civil employment.
Success	It was a clean simple fracture of transverse direction. Hence the suitability for this simple operation.
Death	He was a big man with a fatty heart. The operation was long and difficult. He died 48 hours later, never rallying from the shock of the operation.

Continued on next page

PARTICULARS OF

CASE AND AGE	BONE	CAUSE OF NON-UNION	PERIOD	OPERATION
51 Pte. J. J.	Femur, middle	Displacement	12 months non-union, 3 months healed	Bolted plate... .. ..
52 Pte. E. R.	Femur, neck	Displacement	9 months non-union, 8 months healed	Tibial bone peg .. ..
53 J. R. Age 50	Femur, middle	Displacement	3 months non-union, no wound	Short intramedullary ivory peg .. .. ..
54 Pte. C. H. Age 22	Femur, lower third	Displacement	3 months non-union, wounds unhealed	Lower end was pressing back on popliteal vessels. Bolted plate, very difficult operation
55 Pte. H. E. Age 24	Femur, middle	Displacement	7 months non-union, 6 months healed	Long graft from the fibula (*Figs.* 205, 206) .. ..
56 Pte. A. S. Age 25	Femur, upper end	Gap 2 in.	5 months non-union, 3 months healed	Preliminary excision of scar followed by transfixion extension. Double graft from tibias. One driven into each fragment and then bolted together
57 Lt. L. S. Age 27	Femur, upper end	Displacement	5 months non-union, 3 months healed	Steel cylinder, 9 in. long, pushed down from trochanter into marrow cavity. Removed after 8 weeks (*Figs.* 196, 197, 198)
58 J. R. Age 29	Femur, upper end	Displacement	16 months non-union, unhealed	Steel rod, cross-shaped in section, thrust down the marrow cavity from trochanter (*Figs.* 194, 195)
59 Pte. J. C. Age 24	Femur, upper end	Displacement	10 months non-union, 2 months healed	Had been very septic and a large part of the muscles over fracture had been lost. Steel rod thrust into marrow cavity
60 Pte. W. B. Age 41	Femur, upper end	Displacement	3 months non-union, no wound	Ivory peg, 6 in. long, ½ in. thick, pushed down from trochanter into marrow cavity (*Figs.* 199, 200)

CASES—*continued.*

RESULT	REMARKS
Success	The friable bone was fractured by the bolts. The plate was removed after 4 months. Eventual sound union. Poor function.
Success	Slow restoration of function.
Success	Slow union, but good result after 6 months.
Failure	Moist gangrene of the leg due to injury of the popliteal vessels; amputation. Severe tetanus, cured by anti-tetanic serum.
Success	Much comminution, but no scar of wound. Upper end tilted forward. Smooth healing, but very little new bone formation. Still under observation, walking on crutches 6 months after operation.
Death	Severe shock, from which he died. It was a mistake to operate on 3 large bones at the same time. Lungs, brain, and kidneys showed fat emboli, but though these were abundant, I do not think that they had anything to do with death.
Success	The bone, especially the upper fragment, was too atrophied to take screws. Six months after operation he is walking well with crutches. There is still an unhealed sinus.
Under observation	The rod is still in position, 6 months after insertion. Union is very slowly occurring.
Failure	The wound gave way over site of fracture, and profuse suppuration, not cured by removal of the rod, was set up. Subsequent amputation.
Death	Appeared to do perfectly. Eight weeks after operation developed influenza. Leg swelled, and on being opened was full of blood with a little pus. Death 2 days later. Femur had made a perfect union.

THE TREATMENT OF DISABILITIES OF THE UPPER EXTREMITY IN MILITARY SURGERY.

By Major NAUGHTON DUNN, R.A.M.C., Birmingham.

Of the cases admitted to a military orthopædic hospital, 48 per cent suffer from some disability of the upper extremity. In many, the wounds are healed ; but in practically all there is limitation or loss of movement in one or more of the joints of the limb. Owing to the recognition of the fact that the best artificial arm is a poor substitute for the original, every effort is made to avoid amputation in the acute stage ; it therefore falls to the lot of the orthopædic surgeon to solve many problems of extreme interest and difficulty. The risks incurred in saving limbs abroad are only justified if we in this country can restore them to at least a moderate degree of usefulness. One knows that much disability is inevitable, owing to pressure of work both abroad and at home, but it is important that all surgeons should realize the important principles of treatment, and how and when to apply them.

The hand being the essential part of the upper extremity, I propose to deal first with its disabilities and their treatment. With one exception—suture of nerves—restoration of grasp should be our first endeavour. Once useful movement of the thumb and fingers is procured, the patient's enthusiasm is enlisted, and the surgeon is assured of his active co-operation in any further operative procedure necessary to mobilize or alter the position of the larger joints. An exception to this rule is made in the case of lesions of nerves, mainly because the period necessary for regeneration—a physiological process without which complete functional recovery is not possible—allows ample time for the treatment of the deformity or loss of movement of the joints themselves.

THE HAND.

Direct Injury.—In cases where there has been direct injury of the hand, with ankylosis of one or more joints and general rigidity of all, our first endeavour should be to get as much functional recovery as possible before resorting to any operative procedure ; until the patient has recovered volitional control of what we know to be potentially possible, plastic surgery is contra-indicated. Frequently the patient has had his arm splinted and slung for many months, and treatment by baths, massage, etc., will be necessary. After a few weeks of this, we find one of three conditions in the fingers : Either (1) There has been very marked improvement ; or (2) The periarticular structures have become thickened, œdematous, and tender ; or (3) There is limitation of flexion, due to the shortening of the structures on the extensor aspects of the forearm or hand.

1. In the first case we force the joint a little further than has previously been done, and the definite snap of adhesions is felt. This is an indication that forcible manipulation under an anæsthetic will hasten recovery.

2. In the second class of case, where there has been considerable reaction to movements without anæsthesia, and the joint tends to spring back to its extended position on further forcing, the treatment should be rest, massage, and gradual flexion later.

3. In the third case, the flexion of all joints is free, but it is not possible to combine their movements. With the metacarpo-phalangeal joints in the extended position, flexion of the interphalangeal joints is possible, but when the metacarpo-phalangeal joints are flexed, the interphalangeal joints resist flexion. In this case, again, we must depend on graduated splintage. A short cock-up splint is applied to the wrist and fixed with plaster-

of-Paris, which also maintains the metacarpo-phalangeal joints in flexion. The interphalangeal joints will then be extended, and gradual flexion of these will give the stretching of extensor tendons necessary for a good grasp. If the shortened tendons are involved in scar adherent to the metacarpal bones, the scar should be dissected out and free motion of the metacarpo-phalangeal joints obtained before any suture of the tendons is attempted. Flexion of the metacarpo-phalangeal joints should be maintained until the patient can voluntarily increase the degree of flexion obtained by fixation. Where the thumb is adducted, its position must first be corrected, in order to clear the grasp.

In cases with fair movement, but where further recovery is unduly retarded by the ankylosis of one or more joints, pseudarthrosis may be necessary as a preliminary. Remembering that complete movement of individual fingers is not possible in the normal hand where either the third, fourth, or fifth finger is held fixed in the extended position, pseudarthrosis of one or more of these joints may be necessary to allow the full functional recovery of the others.

Common Disabilities of the Hand directly associated with Injuries of Individual Nerves.

1. *Ulnar Nerve.*—Contracture of the interphalangeal joints of the fourth and fifth fingers, hyper-extension of all the metacarpo-phalangeal joints, with rigidity of the fourth and fifth. This condition is due to contracture of the ulnar half of the flexor profundus digitorum, paralysis of the lumbricales and interossei allowing unopposed action of the extensors, and trophic changes leading to loss of elasticity in the joint capsules. These changes are seldom seen in cases where early use of the hand has been allowed, and are most marked where prolonged disuse has been necessary for other lesions. The treatment of the contractures is the same as will be described later under ischæmic contractures. Once we have corrected the contractures, re-education and the use of the hand will in most cases give us a hand with a strong grasp, and once this is attained there is little tendency to recurrence of deformity.

FIG. 225.—Range of movement in fingers which should be obtained before operating to correct palmar flexion of wrist.

2. *Median Nerve.*—Rigidity in the extended position of the interphalangeal joints of the first and sometimes the second finger, with loss of movement in the terminal phalanx of the thumb. Owing to the loss of sensation in the thumb and index finger, there is a tendency on the part of the patient to nurse rather than use the hand. Once the nerve has been sutured, and the patient encouraged and trained to use the hand, little further treatment is necessary until voluntary power of flexion of the terminal phalanges begins to return, when continuous flexion of the index finger will hasten recovery of function.

3. *Musculospiral Nerve.*—Rigidity of the metacarpo-phalangeal joints. Having successfully sutured this nerve, we should await signs of recovery of voluntary extension of the fingers before deciding that active mobilization of these joints is necessary, as this will frequently have been obtained by daily massage and movements before regeneration occurs, a short cock-up splint being used to maintain dorsiflexion of the wrist and abduction of the thumb.

I need not here discuss the treatment of injuries to peripheral nerves, but wish it to be understood that this follows the recognized lines.

I have discussed mobilization and re-education in the use of the fingers first, because I believe it to be a wise preliminary to any further operation directly affecting the hand,

whether that be tendon transplantation to replace function we know to be permanently lost, or correction of deformity of the wrist which we know will further increase the usefulness of the hand. We do not of course expect complete voluntary closure of the hand with a wrist ankylosed in flexion; but unless we have something approaching the range of the normal hand with the wrist in the flexed position, the treatment necessary to obtain movement in the fingers after the position of the wrist has been corrected will tend to a recurrence of the deformity (*Fig.* 225).

Having obtained free passive movement of the joints of the fingers, and as much voluntary control as possible, we can pass to the consideration of the other conditions limiting function.

THE WRIST AND FOREARM.

The deformities and disabilities of the wrist and forearm should be our next consideration (*Fig.* 226). We wish to obtain voluntary extension and flexion of the wrist, and supination and pronation of the forearm; but as this will only be possible in a few of the cases, we aim at the limited movement or ankylosis being in the position most useful to the patient.

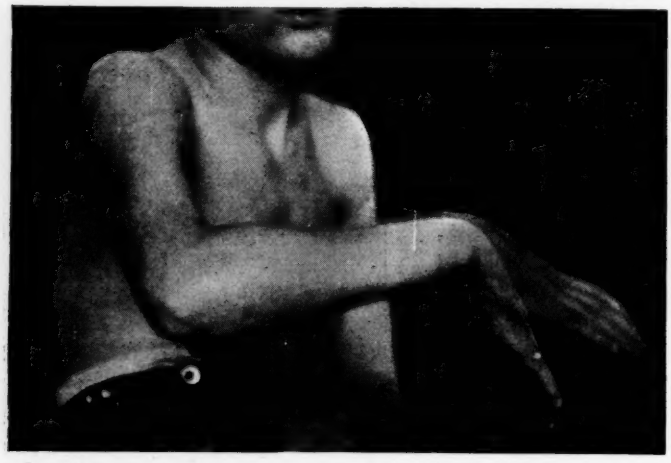


FIG. 226.—Common disabilities of forearm and hand. *Elbow:* Limited movement below right-angle. *Forearm:* Pronated. *Wrist:* Limited movement in flexion. *Fingers:* Stiff in extension.

Let us consider first the pronation and loss of dorsiflexion due to contracture of soft tissues. The previous history of these cases will be usually that of treatment on the internal angular splint, and they will arrive with contracture of elbow, pronation of forearm, the wrist flexed, and the fingers stiff, usually in the extended position. Failing complete restoration of function with treatment in the hydrotherapy, massage, and electrical departments, methods of gradual correction or forced correction under an anæsthetic are still available. The principle of gradual correction is that of overcoming the tension and elasticity of shortened structures by slowly guiding the limb to the desired position. Many splints have been devised for this purpose, but none are necessary if plaster-of-Paris and felt are available.

Having obtained the position of choice, a removable plaster-of-Paris splint should be made to allow movement, and be worn until such time as tendency to re-contracture of the stretched structures is gone. The only sure guide to this is the clinical test which governs the treatment of all scar tissue. The splint is removed first for a short time daily, and use of the limb encouraged. If re-application of the splint is difficult or painful, we must maintain our correction for a further period; but if there is no tendency to recurrence of the deformity, further relaxation may be allowed until the splint is worn at night only, and then entirely dispensed with. Gradual correction will usually be possible where there is limited painless movement; but in cases where there is rigid fixation, one or more anæsthetics and forcible correction will probably be necessary.

Ischæmic Contractures.—Before discussing the cases requiring open operation for their correction, it would be well to describe in detail the correction of ischæmic contractures, which affect mainly the forearm, wrist, and hand. The same principles of treatment apply equally to the contractures from causes which we have already mentioned.

In the severe case the hand is cold and livid, with the wrist flexed and the

fingers contracted; all structures on the flexor aspect of the forearm and hand are shortened, so that such contractile substance as is left in the muscles has no useful sphere of action. We also notice that movement of the wrist towards extension further clenches the interphalangeal joints, while palmar flexion allows their slight relaxation.

Treatment of Ischæmic Contractures (*see Case* 7).—Fully flex the wrist and metacarpo-phalangeal joints; then mould a plaster-of-Paris bandage to fit the palmar surface of the hand and fingers. When this has set, any movement of the wrist towards the straight position will only be possible by the stretching of the structures on the flexor aspect, and this will occur in the order of their tension. Full tension is not a natural condition of any structure of the body, and if we mechanically maintain this condition, nature will assist us in the correction of the deformity by gradual adaptation of the parts to the new conditions. We thus find that in a few days some movement at the wrist is again present, when re-application of the plaster hand-piece will allow further extension of the fingers with the wrist in full palmar flexion.

Having thus corrected the contractures of the hand, a plaster hand-piece is made to fit the hand accurately, the thumb being abducted and slightly forward, the metacarpo-phalangeal joints flexed 20 degrees, and the interphalangeal joints in the extended position. When this is applied to the hand, the wrist can be gradually brought to the straight position by bandaging to an anterior splint. The straight position having been reached, this splint is replaced by a short cock-up splint to obtain full dorsiflexion. The plaster hand-splint serves two useful purposes: first, it prevents contracture of the fingers; in the second place, any pressure applied to it is transmitted to the entire palmar surface of the hand, thus avoiding sores from local pressure.

FIG. 227.—To show difficulty in writing with ankylosis in full supination.

Having attained full dorsiflexion of the wrist with the fingers extended, the splint may now be removed daily for electrical treatment of the extensor muscles, and as voluntary control of these increases, the clinical test of removing the splint entirely for short periods is again applied and functional use of the hand allowed. The splint is worn at night for some months longer to ensure a permanent result. If, after full extension of the wrist and fingers is complete, stiffness of the metacarpo-phalangeal joints is present, a short cock-up splint and metal finger splints to fix the interphalangeal joints are used until movement at the metacarpo-phalangeal joints has been obtained.

Open Operation.—In certain cases further mobility and control of the digits can only be obtained after open operation to improve the position or increase the movement of other joints of the limb, and we will take these in the direct order of their effect on our prime object, viz., a useful hand.

1. *Ankylosis of the Wrist.*—This may or may not be associated with loss of movement at the lower radio ulnar joint. If pronation and supination are free, with ankylosis at the radio-carpal joint in the flexed position, we should be careful to confine our operative procedure to the radial side of the joint. A posterior incision, with removal of a small wedge of bone from the dorsal aspect, will give us the dorsiflexed position, which must be maintained by splintage until complete grasp has been obtained, as the treatment

necessary for obtaining this tends to draw the wrist again into flexion. Ankylosis of the wrist in a position of 40 degrees dorsiflexion is no serious disability.

2. *Ankylosis of Wrist and Lower Radio-ulnar Joint.*—If both the joints are ankylosed, before operation we must decide which is the position of choice for the patient, as operation to regain mobility of the joint, though it may be successful, cannot always be relied on.

Although as a rule of treatment full supination is excellent, it is not always the position of choice where ankylosis results. In general, the best position for ankylosis is midway between pronation and supination—i.e., on flexing the elbow, the back of the thumb is brought to the mouth. In the case of a clerk, the position of the hand in writing—that is, a few more degrees pronation—will usually be preferred for the right hand (*Fig.* 227).*

Non-union of Radius and Ulna.—Non-union of one of the bones of the forearm has been remarkably frequent, and I have had three cases in which a flail limb resulted from non-union of both. The hand is attached to, and articulates mainly with, the radius, so that loss of the support of the latter owing to non-union is associated with radial deviation of the hand and considerable weakness of grasp. In the case of non-union of the ulna, the weakness, though present, is less marked, and there is little deformity.

Most ununited fractures of the radius require bone grafting, but some ununited fractures of the lower third of the ulna or of the olecranon show so little disability that this is not necessary. Where the lower fragment of the radius is less than an inch in length, shortening of the ulna to correct radial deviation and allow direct union of the radial fragments gives a good result.

Before operation in these cases, mobility of the hand should be restored, the radial deviation of the hand corrected, and the forearm fixed for a time in the supine position. Unless this is first secured, there will be strain on the graft after operation or union will occur in the position of deformity, which will necessitate further operation for the best result.

With ununited fractures of both bones, a shortening of both to allow direct union, with a bone graft of the ulna to ensure adequate fixation, is the procedure of choice.

We must also remember that where ankylosis of either the superior or inferior radio-ulnar joints is present, any movement of pronation or supination taking place at the site of fracture will be lost if union of the fragments is re-established.

Bone Grafting.—Success depends on: (1) Asepsis; (2) Adequate contact of raw surfaces; (3) Efficient fixation. If there has been severe sepsis, all wounds should be healed for six months, and scar tissue excised where possible.

The preliminary excision of scar tissue serves three useful purposes: (1) It enables us to judge of the probability of grafting bone without the recrudescence of sepsis; (2) It removes tissue of low vitality which will itself tend to necrose and slough after its blood-supply is further reduced; (3) Its removal allows healthy vascular tissue to surround the bone graft.

Care should be taken that the bed for the graft is cut on the surfaces of the fragments that will be in continuity when the limb is in the desired position. As this is usually supination, we should arrange for this position to be maintained from the time the incision is made until the fixation splints or plaster have been applied.

In order to ensure adequate contact and fixation, the graft should be as long as anatomical conditions allow, and should be just wider than the bed which has been cut for it, so that, when wedged into place, it is gripped firmly by the lips of the fragments, and further fixation is not necessary. It should consist of periosteum,

* Where loss of pronation and supination is due to ankylosis of the inferior radio-ulnar joint, the operation lately devised by Captain Baldwin, of San Francisco, is probably the best. His operation consists of the removal of a portion of the lower third of the ulna, in order to obtain a false joint which allows voluntary pronation and supination.

cortex, and endosteum, and be of sufficient strength itself to withstand the strain of function when union is complete.

Fixation by means of splints should usually be maintained continuously for a period of three months.

THE ELBOW-JOINT.

The conformation of the articular surfaces of the elbow-joint allows of movement only in the antero-posterior direction. The superior radio-ulnar joint communicates with it, and is necessarily involved in general arthritis of the joint. If the radio-humeral or radio-ulnar joint is ankylosed, pronation and supination are not possible (*Fig.* 228). The muscles producing these movements are not adapted for controlling lateral movements, so that often the best result to be obtained after severe wounds involving the joint will be the greatest degree of movement in the antero-posterior direction, with stability on lateral strain. Cases will arise where free flexion and extension is essential for the patient, and if lateral stability could be assured, this would be best for all; but for the man who depends on the strength of his arm for his livelihood, an ankylosed joint in the position of choice should, in my opinion, only be subjected to operation when the facts have been laid clearly before the patient. My experience has been, that if you are to guarantee free movement of the joint, so much bone must be resected that lateral mobility will interfere with the strength of the limb (*Fig.* 229). One knows that in the acute stages free removal of bone may be necessary to save life or limb; but recent literature advocating free removal of bone as a routine measure in gunshot wounds of the elbow is not justified by the end-results which find their way to military orthopædic hospitals. It has in my experience been necessary to operate more frequently to increase the stability than the mobility of the joint.

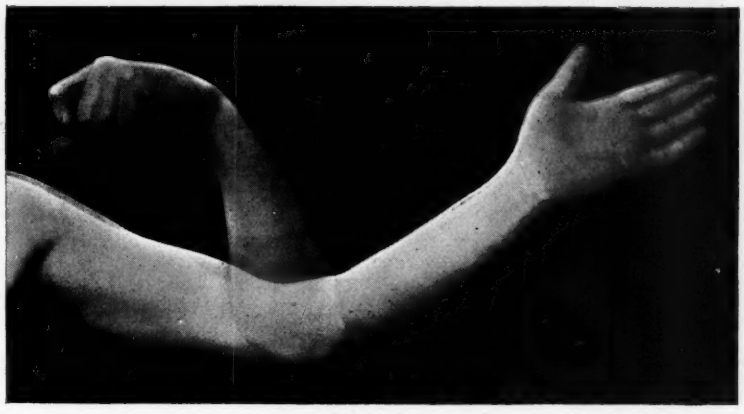


FIG. 228.—Showing range of movement obtained by conservative treatment.

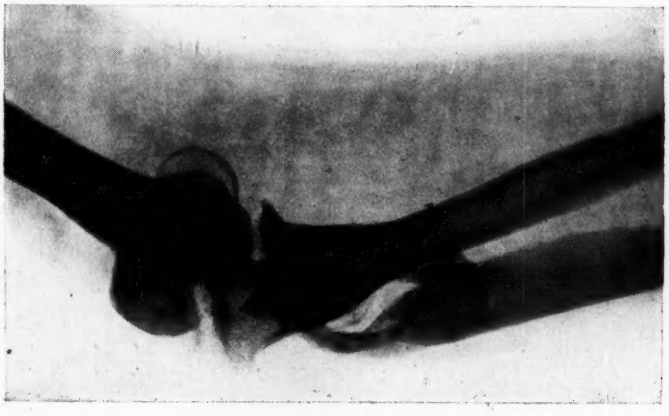


FIG. 229.—Same patient as *Fig.* 228.

The flail elbow-joint without voluntary control and with wide separation of the bone surfaces is one of the most difficult problems to deal with surgically, and often ends in fixation by external splintage. Stability of the elbow-joint is dependent more on the articulation with the ulna than the radius, and a good functional result is often

seen with absence of the external condyle. [One does see cases of excision which result in fair control and mobility, but this result seems to be more assured by an operation of choice when the question of sepsis has been eliminated. So many cases of apparently hopeless destruction end in fair movement if treated on conservative lines, that bone should only be removed to meet the immediate necessity of the case.

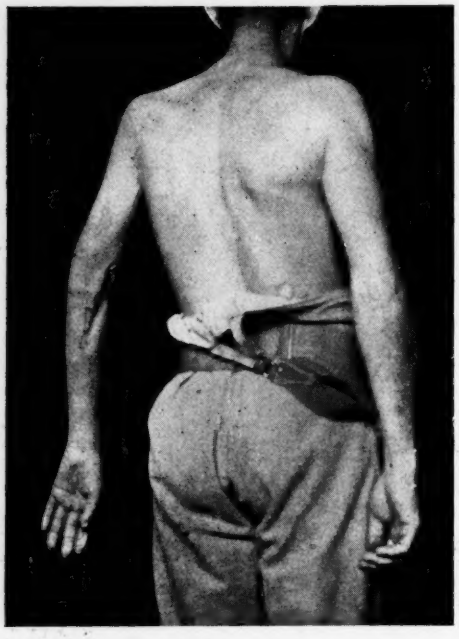


FIG. 230.—Photograph to illustrate ankylosis of elbow in extension with pronation of forearm. Points to be guarded against in prolonged treatment in Thomas arm splint.

Let us consider, then, the conservative treatment of wounds of the arm with a view to obtaining the maximum movement of the elbow-joint, or, if ankylosis is inevitable, the best position for this (*Fig.* 230).

The essential treatment will be rest, often for some months, and the position of rest must be guided in the first place by the condition of the wounds. For efficient treatment of these, full extension and fixation in the Thomas arm splint is commonly used until the acute sepsis has been controlled or the fracture has begun to show signs of union, when the arm should be gradually flexed, supination being assured from the beginning. If the fully flexed position with supination could be obtained and maintained until the conditions demanding rest no longer existed, a large number of cases would not require such prolonged treatment in hospitals in this country. Cases with pronation of the forearm and limited movement below a right angle are so common, that every effort should be made to guard against them as early as possible. Once we have secured full supination and flexion at the elbow-joint, any movement which results will be in the best position, and gravity and function will both aid in its increase. In the later stages, considerable force will often be required to obtain this position, and it will usually be safer to use gradual means, and if an anæsthetic is necessary, not to attempt too much at one time, because of the risk of fracture of the olecranon and the recrudescence of sepsis. We then wait until all sign of reaction has gone before applying the clinical test which will decide whether it is now safe to allow movement. When the biceps—previously weak—has recovered its tone, and there is no peri-articular thickening or tenderness, the collar and cuff (*Fig.* 231) which maintain the position are relaxed, allowing limited extension. If the patient can voluntarily resume the position of previous fixation, further liberty is allowed; and when movement from full flexion to a right angle is free, and the patient has learned to use the joint again, function and gravity are now both allies in obtaining further increase of movement.

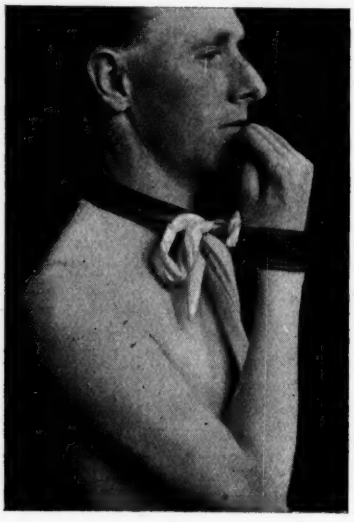


FIG. 231.—Showing Thomas's collar and cuff to maintain flexure of elbow and supination of forearm.

Where ankylosis is to be expected, the position of choice—usually an angle of 100 degrees, with the forearm midway between pronation

and supination—should be maintained until the ankylosis is sound. Special cases will arise where another position is desired.

Bone Blocking Flexion.—This should be removed, by operation if necessary, as soon as conditions permit, and the acutely flexed position obtained.

Myositis Ossificans.—The history is usually that of movement gradually becoming more limited with use. *X* rays show new bone formation on the flexor aspect, frequently in the substance of the brachialis anticus.

Treatment.—The elbow should be kept at rest in flexion until ossification is complete, when movements can be gradually recommenced. Any forced passive movements will only aggravate the condition, and any operation for its removal before this stage is reached is doomed to failure.

THE SHOULDER-JOINT.

Wounds involving the shoulder-joint require our special attention at an early stage to secure a good result. They are frequently complicated by paralysis of the deltoid and much laceration of the soft parts. In some cases two or three inches of the upper end of the humerus have been removed. The end-result of these cases is usually either a flail limb without power of abduction (*Fig.* 232), or ankylosis in the adducted position, requiring further operation to get a useful range of movement.

FIG. 232.—Showing common disability following excision of upper end of humerus.

In this joint, perhaps more than any other, the cicatrization of scar tissue, so often responsible for grave and irreparable deformity, may in certain cases, if carefully guided, play an important part in the restoration of function.

As soon as the acute sepsis is past, the limb should be fixed with the shoulder abducted 70 degrees, and with the elbow-joint just in front of the coronal plane of the body, so that when flexed the palm of the hand easily reaches the mouth. Plaster-of-Paris, with windows cut to allow of dressing, should be applied so as to keep the upper end of the humerus in close proximity to the glenoid cavity. This position is maintained until bony or short fibrous ankylosis results, when, the sterno-clavicular joint being the centre of motion, an almost complete range of abduction and adduction may be obtained.

The abducted position of the shoulder is also indicated in all cases where this movement is likely to be limited, either by new bone formation in the neighbourhood of the great tuberosity, or fracture of the acromion process. It also allows relaxation and recovery of a weakened deltoid, and prevents contracture of the axillary folds, which is so common after general inflammation of the upper limb.

Where the muscles controlling the scapula are paralyzed, postural relaxation with electrical treatment should be persevered with, unless recovery is impossible from the nature of the injury, when a shoulder-brace to control its movement will allow a more powerful use of the limb.

Where the scapula is fixed to the ribs as the result of severe injury, movement at the shoulder-joint will vary with the degree of its rotation. Operation to alter this will not as a rule be indicated, as, with the scapula in its position of rest, abduction of the shoulder to a right angle is still possible.

THE SURGERY OF NERVES AND TENDONS IN RELATION TO JOINTS.

Gunshot wounds often result in the loss or destruction of several inches of the main nerves, and the possibility of suture is frequently dependent on our being able to obtain the necessary relaxation of the joints of the limb by posture. The positions usually required are flexion of the wrist and elbow, with or without pronation of the forearm, and adduction of the shoulder. These positions, if present, should not be altered until suture of the nerves is assured, and if possible they should be obtained before this is undertaken. After suture is completed, the position of the joints should be maintained for two weeks before gradual, and one month before forcible, alteration of their position is allowed.

Where it has not been possible to obtain direct continuity of the nerves, there still remains nerve crossing, nerve grafting, or tendon transplantation to fall back upon. My own experience of the first two has been unfavourable, and I now depend entirely on the last.

One of the most important factors for success in tendon transplantation is the condition of the joints directly affected.

I have recommended nerve suture as the prime consideration in the treatment of the joints of the upper extremity, and have no hesitation in emphasizing the importance of tendon transplantation as the final operation to be undertaken in the treatment of disabilities of these joints. For it to be successful, we must have strong healthy muscles, and these will only be available if the joints they control have allowed of their free development.

DETAILS OF CASES.

It has only been possible in a short article to give a bare outline of so important a subject, and I therefore append a detailed account of nine cases, with illustrations, in the hope that they may help to demonstrate the points on which stress has been laid.

Case 1.—Pte. H. **Gunshot wound of left arm**, June, 1916.

Condition on Admission, May, 1917.—Ununited fracture just above elbow. Ankylosis of elbow-joint. Lesion of musculospiral and ulnar nerves; flexion and rigidity of wrist and fingers.

June 6, operation. Musculospiral nerve: separation 2 in.; suture allowed by flexion at site of fracture. Ulnar nerve: transferred to flexor aspect of joint, and also sutured. Oct. 23, fixation of ununited fracture by bone graft; plaster-of-Paris fixation of shoulder and elbow. Nov. 27, correction of contracture of hand by graduated splintage. Jan. 18, 1918, electrical treatment and massage of all muscles of limb commenced.

Note.—Had the nerve injury not been so severe, the treatment of the contracture of the hand deformity with temporary fixation of the elbow in plaster would have preceded the bone graft.

Failing recovery in these nerves, no operation of tendon transplantation would be undertaken until the full potentialities of recovery have been obtained in the muscles supplied by the median nerve. It might then be advisable to ankylose the wrist in dorsiflexion as a

preliminary, in order to enable us to use the limited muscles available to the best advantage.

Case 2.—L.-Cpl. D. **Gunshot wound of wrist, Jan. 7, 1917.**
Wounds healed March 10.

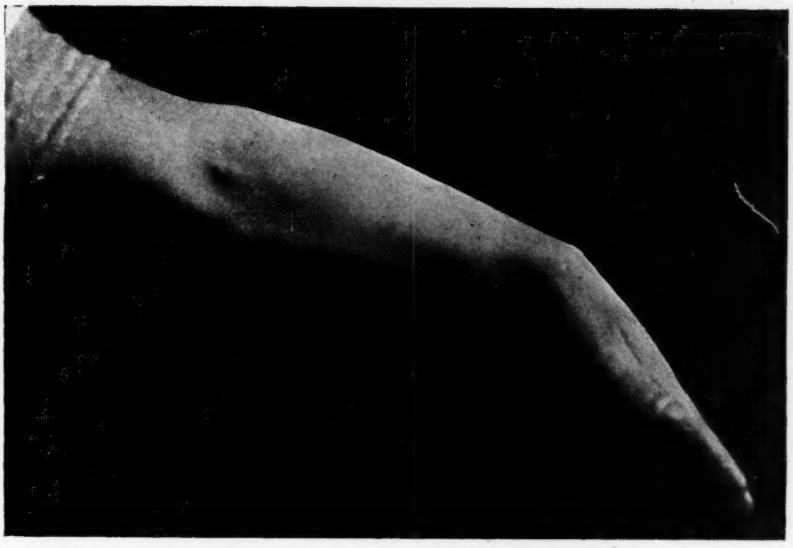


FIG. 233.—*Case* 2. Showing condition on admission, April 2. Wrist ankylosed in flexion; forearm pronated; metacarpo-phalangeal joints rigid in extension.

FIG. 234.—*Case* 2. Showing fixation in plaster after forcible supination and partial dorsiflexion of wrist.

FIG. 235.—*Case* 2. Aug. 10. Showing use of short cock-up splint to maintain dorsiflexion of wrist while movement of fingers is obtained.

Condition on Admission, April 2.—Ankylosed wrist in flexed position (*Fig.* 233); forearm allowing 10 degrees movement in prone position. Metacarpo-phalangeal joints rigid in extension,

FIG. 236.—*Case* 2. Sept 9. Showing range of movement obtained.

due to sepsis and involvement of extensor tendons on dorsum of wrist.

April 11, anæsthetic; flexion of metacarpo-phalangeal joints; fixation in plaster-of-Paris. When swelling and reaction subsided, gradual flexion of interphalangeal joints gave the necessary stretching of structures on the extensor aspect. Flexion of metacarpo-phalangeal joints maintained for four weeks, then free use of the fingers encouraged. June 4, cuneiform osteotomy, radiocarpal joint, to allow of 45 degrees dorsiflexion of wrist. Fixation in supination and plaster-of-Paris (*Fig.* 234). Aug. 10, plaster-of-Paris removed; short cock-up splint applied to allow more free use of the hand (*Fig.* 235). Sept. 9, photograph shows movement obtained (*Fig.* 236).

***Case* 3.—Pte. H. Gunshot wound of left forearm, Oct. 26, 1915.**

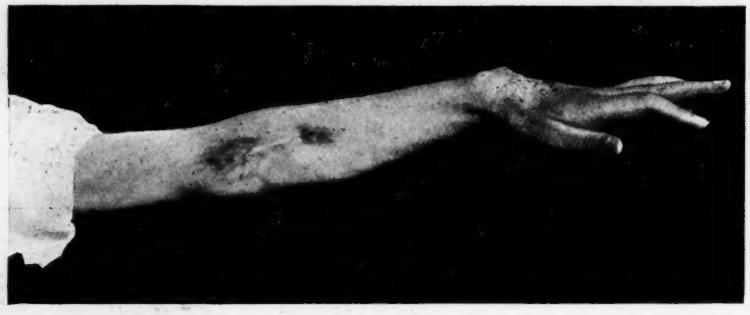


FIG. 237.—*Case* 3. Photograph to show radial deviation of hand and deformity of the wrist due to ununited fracture of radius and scar-contracture.

FIG. 238.—*Case* 3. Showing plaster hand-piece and short cock-up splint used for gradual correction of deformity of the wrist.

Condition on Admission, Dec. 14, 1916.—Ununited fracture of radius, with radial deviation of hand, and scar contracture of structures on flexor aspect of forearm causing anterior subluxation at wrist-joint; loss of dorsiflexion and pronation of forearm (*Fig.* 237).

Dorsiflexion of wrist obtained by graduated splintage (*Fig.* 238). March 6, 1917, anæsthetic; supination of forearm and correction of radial deviation of hand. Fixation in plaster. April 7, bone graft of radius; fixation in plaster-of-Paris for three months, allowing free use of fingers. Six months after the last operation a strong, useful hand resulted, with all movements controlled.

Case 4.—Pte. B. **Flail elbow** (*Figs.* 239, 240).
X ray shows absence of lower end of humerus, head of radius, and upper end of ulna. Moulded leather splint to allow use of limb.

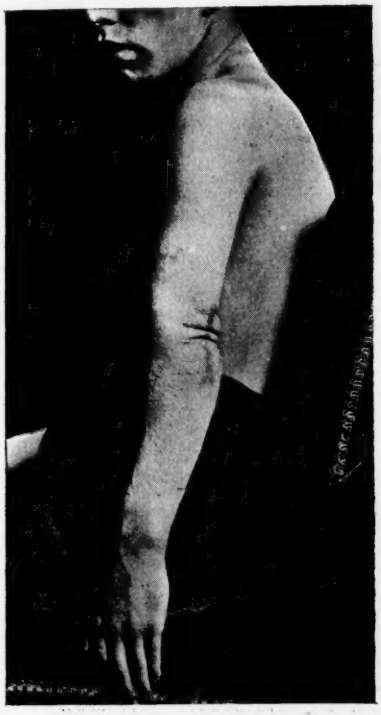


FIG. 239.—*Case* 4. Showing flail elbow following early excision.

FIG. 240.—*Case* 4. Fixation of elbow by external splinting, to allow use of hand.

FIG. 241.—*Case* 5. Showing new bone formation in front of elbow, limiting flexion.

FIG. 242.—*Case* 5. Showing range of movement obtained after treatment in acute flexion.

Case 5.—Pte. J. R. **Gunshot wound of right elbow, Oct. 7, 1915.**

June 5, 1916, elbow-joint was excised. In splint two weeks, sling five weeks. Massage and passive movement commenced seven days after operation.

Condition on Admission, Aug. 12.—Twenty degrees passive movement at an angle of 140 degrees. Pain on forcing movement. *X* rays show new bone formation in front of joint (*Fig.* 241).

Aug. 16, elbow flexed to 48 degrees under anæsthetic. Collar and cuff applied. Oct. 4, has 15 degrees movement to acute flexion. Arm to be gradually dropped. Nov. 20, photograph shows range of movement on discharge five months ater (*Fig.* 242).

Case 6.—Pte. P. **Shrapnel wound of left elbow, Dec. 12, 1916.**

Four operations for removal of bone.

Condition on Admission, April 2, 1917 (*Fig* 243).—Discharging sinus; fusiform swelling of joint. Arm held with elbow at angle of 160 degrees; 45 degrees passive movement, no voluntary control. Forearm in pronation; attempt to supinate painful. Unable to dorsiflex wrist. Fingers rigid.

Gradual supination of forearm and flexion of elbow with Jones's elbow splint, with wrist gradually dorsiflexed on short cock-up splint (*Fig.* 244). Dec. 3, photograph shows voluntary movement obtained (*Fig.* 245).

FIG. 243.—*Case* 6. Condition on admission.

FIG. 244.—*Case* 6. Showing use of Jones's elbow splint to gradually supinate forearm and flex elbow.

FIG. 245.—*Case* 6. Showing flexion and range of movement obtained eight months after admission.

Case 7.—Pte. L. **Ischæmic contracture. Gunshot wound of right arm, Feb. 5, 1915.**

FIG. 246.—*Case* 7. Ischæmic contracture following gunshot wound of right arm. Condition on admission.

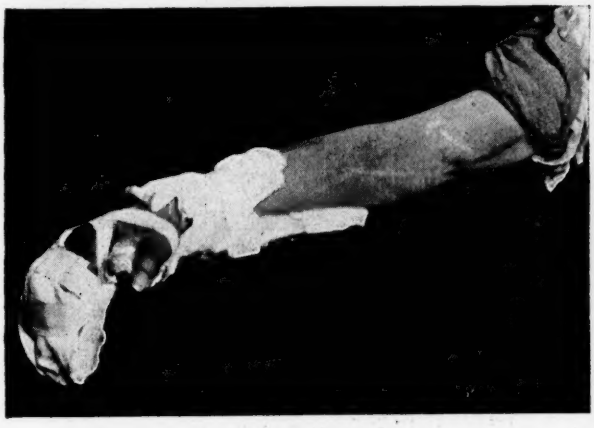


FIG. 247.—*Case* 7. Showing method of gradual correction of contractures by plaster hand-piece and anterior splint.

FIG. 249.—*Case* 7. Showing short metal splints used to maintain extension of the interphalangeal joints while movement at the metacarpo-phalangeal joints is obtained.

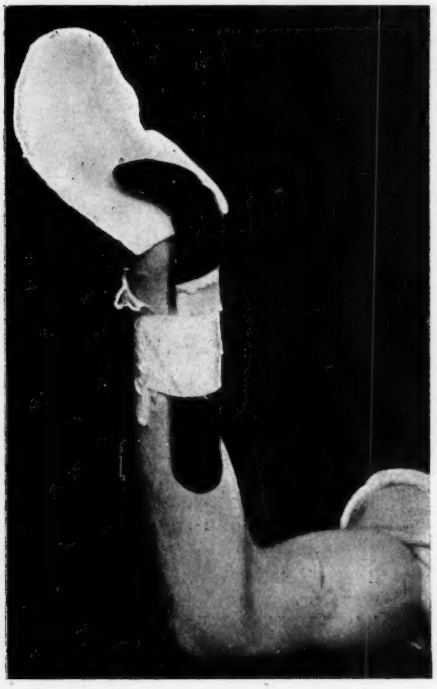


FIG. 248.—*Case* 7. Showing complete correction of contractures by plaster hand-piece and short cock-up splint.

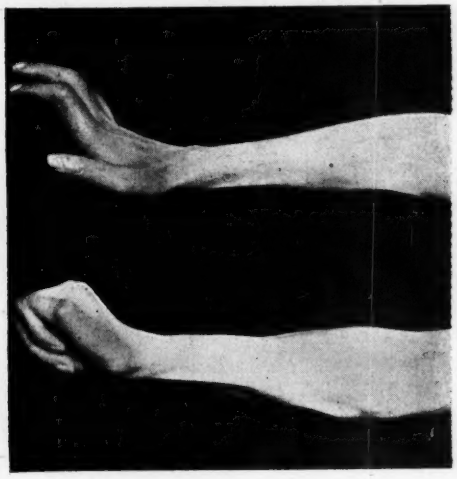


FIG. 250.—*Case* 7. Showing range of voluntary movement obtained nine months after admission.

Condition on Admission, June 26, 1916.—Right hand livid and contracted; wrist flexed; metacarpo-phalangeal joints hyperextended; phalanges in intense flexion (*Fig.* 246).

July 17, gradual correction of contracture by plaster-of-Paris hand-piece and anterior splint (*Fig.* 247). Nov. 10, complete dorsiflexion obtained by plaster-of-Paris hand-piece and short cock-up splint (*Fig.* 248). Extension of interphalangeal joints maintained while flexion of metacarpo-phalangeal joints is obtained (*Fig.* 249). March 1, 1917, photographs show the degree of voluntary opening and closing of the hand obtained (*Fig.* 250).

Case 8.—Bugler E. **Gunshot wound of left shoulder,** Sept. 14, 1916.
Condition on Admission, Nov. 7.—*X* rays show much swelling and pain (*Fig.* 251), with discharging sinus. No involvement of main nerves.

FIG. 251.—*Case* 8. Gunshot wound of shoulder. Condition on admission seven weeks later, showing absence of upper end of humerus.

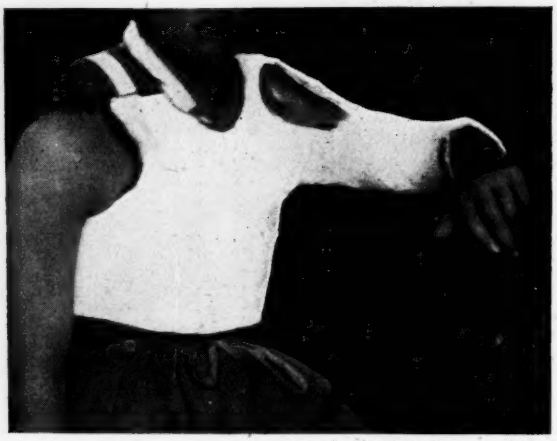


FIG. 252.—*Case* 8. Showing plaster fixation with a view to ankylosis of shoulder in the abducted position.

Nov. 25, arm fixed in abduction; plaster-of-Paris, with window for dressing (*Fig.* 252). Jan. 11, 1917, removal of sequestrum. *X* rays show position of ankylosis obtained (*Fig.* 253). Oct. 8, photograph shows range of movement obtained (*Fig.* 254).

FIG. 253.—*Case* 8. Showing ankylosis of humerus and scapula.

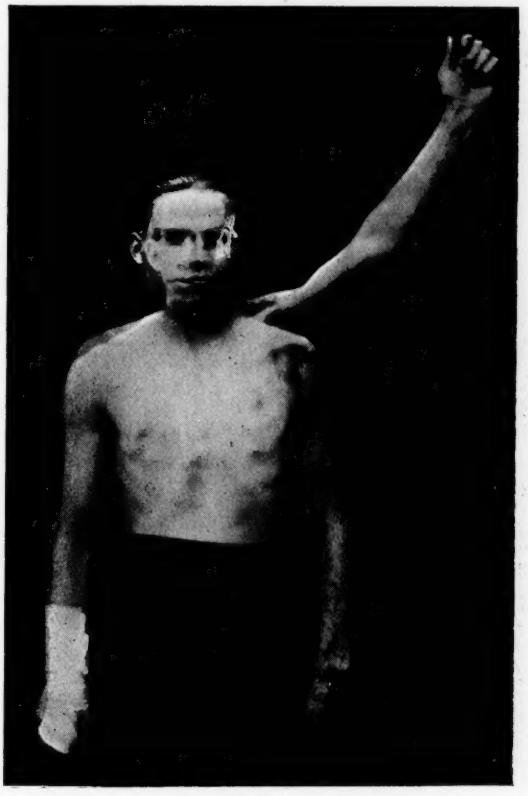


FIG. 254.—*Case* 8. Showing range of scapular movement obtained.

FIG. 255.—*Case* 9. Gunshot wound of shoulder, showing condition on admission three weeks after injury.

Case 9.—**Pte. E. Gunshot wound of left shoulder, May 20, 1917 (*Fig.* 255).**

***Condition on Admission*, June 12.—*X* rays show absence of upper third of humerus, head of scapula, acromion process, and outer portion of clavicle (*Fig.* 256).**

Aug. 21, photograph shows scar tissue contracted to thin line (*Fig.* 257).
This patient is now able to raise his arm from the splint voluntarily (*Fig.* 258). The ankylosis is one of scar tissue between the upper end of the humerus and shoulder girdle.

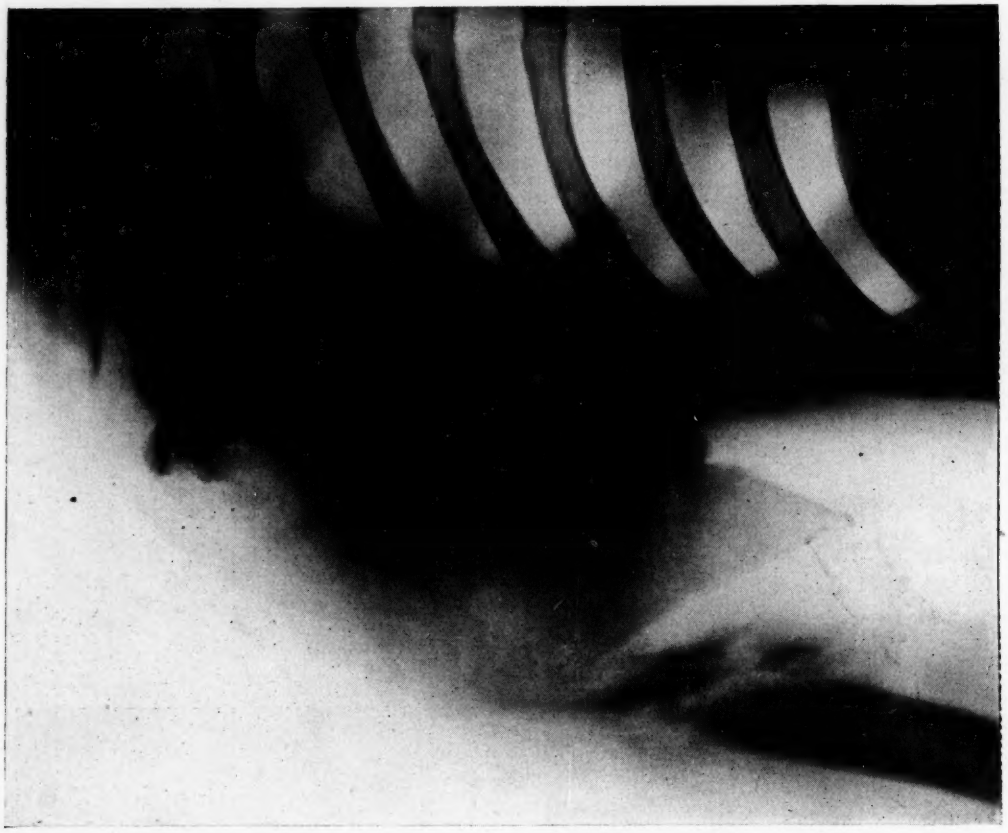


FIG. 256.—*Case* 9. Showing absence of upper third of humerus, head of scapula, acromion process, and outer portion of clavicle.

FIG. 257.—*Case* 9. Showing position of fixation and contracture of scar.

FIG. 258.—*Case* 9. Showing approximation of shaft of humerus to shoulder girdle nine months after injury.

THE RESULTS OF PRIMARY EXCISION FOR WOUNDS OF THE ELBOW-JOINT.

By Captain A. EISDELL MOORE, R.A.M.C.

During the last year a considerable number of wounds in the region of the elbow, with fractures involving the joint, have been treated by a primary excision of the elbow-joint at the casualty clearing station. As a result, the staffs of the orthopædic hospitals are being called upon to treat an increasing number of flail elbow-joints, a disability which causes great impairment of function, and which is difficult to correct satisfactorily.

The following remarks are based on eleven consecutive cases (as set out in table form on the following page) recently treated at the Bristol orthopædic centre, and which had had primary excision of the elbow-joint performed at the front. It is doubtful if in more than two patients (*Cases* 9 and 10, *Fig.* 266) the result can undeniably be called good. One appreciates that because this is an orthopædic centre the cases seen probably include the more unsatisfactory results, still the publishing of them may be of use to the surgeon at the C.C.S.

Fig. 259.—*Case* 1. Pte. B. Extensive primary excision.

The Relation between the Amount of Bone Removed and the Subsequent Functional Result.—In classifying these cases one realizes at once that the final functional result depends mainly on the amount of bone that has been removed. Colonel Mansell Moullin[1] advocates primary excision provided sufficient bone is removed, and advises a thorough removal of the articular ends of the humerus, radius, and ulna, whilst Major Swan[2] and Captain Sheppard[3] advocate a less extensive operation; the following cases support fully the latter opinion.

Of the eleven cases given, ten have flail elbows to a greater or lesser degree, and the uselessness of the limb is—if the length of time from the original wound be taken into account—in almost direct proportion to the amount of bone removed. The cases are arranged according to the extent of the operation, and it will be noted that as the amount of bone removed decreases so does the functional result improve. Thus *Case* 1, *Fig.* 259, shows a gap of 4½ inches between the cut ends of the humerus, and radius and ulna. Undoubtedly some of this is due to the stretching of the soft parts; still, the original removal of bone must have been very extensive. Naturally the elbow-joint, as such, is useless.

Case 11, *Fig.* 267, shows an ankylosis—the result of removing too little bone—so from this series of eleven, one would gather that the tendency in this operation is at present to remove too much bone rather than too little.

TABLE SHOWING THE RESULTS OF ELEVEN CASES OF

Case	Name	Type of Excision	Gap by *X*-rays	Time after Wound when Report made	Time taken for Wound to heal	Resulting Joint	Passive Movement			
							Flexion	Extension	Lateral Internal	Lateral External
1	Pte. B., *Fig.* 259	Humerus: lower end Radius: head and tubercle Ulna: olecranon	4½ in.	6 mths.	2 mths.	Flail	Full	210°	90°	90°
2	Sgt. M.	Humerus: lower end Radius: head Ulna: olecranon	2 in.	3 mths.	2½ mths.	Flail	Full	210°	50°	70°
3	Pte. S., *Figs.* 260, 261	Humerus: lower end Radius: head Ulna: olecranon	2 in.	8 mths.	1½ mths.	Flail	Full	190°	60°	90°
4	Lt. J., *Figs.* 262, 263, 264	Humerus: lower end Radius: head Ulna: olecranon	2 in.	10 mths.	1 mth.	Flail	Full	200°	70°	90°
5	Pte. S.	Humerus: lower end Radius: untouched Ulna: olecranon	1⅛ in.	5 mths.	2 mths.	Flail	Full	190°	90°	90°
6	Pte. P., *Fig.* 265	Humerus: lower end Radius: untouched Ulna: untouched	¾ in.	9 mths.	6 mths.	Flail	Full	160°	60°	90°
7	Rfm. A.	Humerus: lower end Radius: untouched Ulna: untouched	¾ in.	5 mths.	3 mths.	Flail	Full	210°	90°	90°
8	Pte. B.	Humerus: lower end; much new bone formed Radius: untouched Ulna: untouched	⅝ in.	5 mths.	1½ mths.	Flail	Full	200°	60°	20°
9	Pte. B.	Humerus: below epicondyle Radius: artic. surface Ulna: olecranon process	in.	9 mths.	6 mths.	Weak	Full	120°	Nil	30°
10	Pensnr. D. *Fig.* 266	Humerus: above epicondyle Radius: untouched Ulna: untouched	1 in.	7 mths.	4 mths.	Weak	Full	200°	30°	30°
11	Bdr. E., *Fig.* 267	Humerus: artic. surface Radius: artic. surface Ulna: artic. surface	—	8 mths.	7 mths.	Ankylosed	Nil	Nil	Nil	Nil

Case 12, Pte. P. (*Figs.* 268, 269, 270), is one in which arthroplasty was performed eleven

PRIMARY EXCISION FOR WOUNDS OF THE ELBOW-JOINT.

ACTIVE MOVEMENT	HAND GRIP	REMARKS
None	Good	Forearm muscles arising from humerus formed new attachment to forearm bones, and flexion action of supinator thus lost.
None	Very weak	
Active to 70°	Good	Supported in plaster in early treatment. Marked overriding of bones in voluntary flexion.
Active to 90°	Fair	Gap between ends of bones decreased rapidly on wearing support.
None	Fair	Complicated by ulnar paralysis. *Capsulorrhaphy* performed 5 months after wound. 7 months after wound had 30° voluntary flexion, and lateral mobility decreased to 30° internally and 30° externally.
Active to 110°	Fair	Complicated by ulnar paralysis. *Capsulorrhaphy* performed with ulnar suture 9 months after wound. 12 months after wound active flexion to 60°, lateral mobility decreased to 10° internally and 20° externally. Some grating on extension.
Good power	Good	
None	Fair	After support for 2 months (5 months after wound till 7 months after wound) voluntary flexion to 60° returned.
Complete, but with difficulty	Good	Supported in plaster in early treatment. In voluntary flexion arm supinated first and then flexed, mostly by means of supinator longus.
Active to 60°	Good	Marked tendency for humerus to override outwards.
Nil	Good	Treated in a straight Thomas splint after primary excision. Operation 8 months after wound to repair ulnar nerve. Excess of callus removed and arm flexed. No attempt at arthroplasty, this being left till later date.

months after the wound, and is included for comparison with the above primary excisions.

Method of Limited Excision.—Of course it is impossible to lay down definite rules for any war surgery, and the amount of bone removed must depend largely on the amount of comminution. Yet I would urge that the lines for excision follow Captain Sheppard's method as far as possible; that is to say, the lower end of the humerus is rounded off above the epicondyles, and the radius and ulna are preserved intact. If comminution extends beyond this line there is a great temptation to remove more bone; but it is better to leave this as far as possible, and to cover in the ends of the comminuted bones with a muscle-fascia flap in the same way as is done in performing an arthroplasty. A comparison between *Cases* 1 (*Fig.* 259) and 6 (*Fig.* 265) brings out this point; all comminuted bone was removed in *Case* 1, whilst in *Case* 6 the lower end of the humerus, although badly broken, was left *in situ*, and though it forms no ideal articular surface, the functional result obtained is much better than with *Case* 1. *Case* 4 (*Figs.* 262, 263, 264), where the *x*-ray showing the original injury is available, is also instructive. A piece of shell is seen lying in the comminuted

FIG. 260.—*Case* 3. Pte. S. Bones separated in extension.

FIG. 261.—*Case* 3. Pte. S. Bones overriding before flexion occurs.

lower end of the humerus. The excision performed included the humerus, the radius, and ulna, and the result is not good. One feels that had the operation been limited to the removal of the lower end of the humerus, the patient would have had a much more serviceable joint.

Relation of the Extensive Operation to Sepsis.—It has been argued that wide excision is the best treatment from the point of view of controlling sepsis. In this series only one case healed within a month, the others give an average of over three months. This is not rapid healing; but certainly the more bone removed the more speedy is the first closure of the wound. This, however, by no means compensates for the resulting loss of function.

Again, one cannot but feel that there is a definite risk in the extensive opening up of raw bone surfaces in the presence of sepsis, and also that the sepsis may in itself defeat the real purpose for which primary excision is performed, by stimulating the osteogenetic power of the bone. A glance at the radiogram of *Case* 11 (*Fig.* 267)

shows the large amount of new bone thrown out. It is probable that if an excision of the same extent as was done in this case primarily, in the presence of sepsis, had been done later when the sepsis had cleared up, a movable joint would have been obtained.

The Ability to Preserve Muscular Attachments in the Limited Excision.—In regard to the preservation of muscular attachments, the importance of leaving the

FIG. 262.—*Case* 4. Lt. J. Before operation.

FIG. 263.—*Case* 4. Lt. J. During treatment after primary excision. Drainage tube *in situ*.

FIG. 264.—*Case* 4. Lt. J. After treatment by support.

triceps has been noted in many papers; but less attention has been paid to the equally important point of leaving the origin of the supinator longus. *Case* 9 provides a good example. The patient in flexing his elbow uses his supinator longus considerably more than his biceps. To preserve the origin of the supinator longus is of increased importance, of course, if the radius is badly comminuted at its upper end. Considering that the origin of the supinator longus extends high up the external supra-condylar ridge, it is seldom necessary to interfere with this muscle at all in dealing with a wound limited to the elbow-joint. Another case (*Case* 1) where the origin of the muscle has been removed shows also that it is useless as a flexor of the elbow in its new attachment to the radius, although the patient has a strong wrist and hand from the new attachment of flexors and extensors of the wrist and fingers.

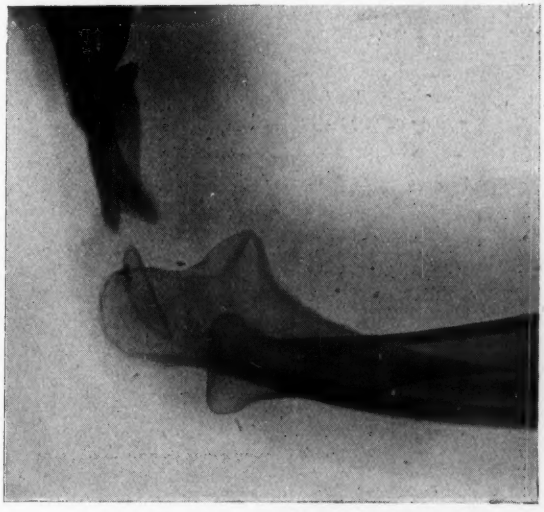


FIG. 265.—*Case* 6. Pte. P. Comminuted lower end of humerus has been preserved.

The Resulting Flail Joint.—An analysis of the ten cases which developed flail-joints after primary excisions shows that :—

1. Passive movement is usually possible from full flexion to about 20 degrees over full extension, and lateral mobility varies from 20 degrees externally only to 90 degrees both internally and externally. This excessive lateral movement is a great disability, the forearm tending to drop downwards when the upper arm is abducted, and so practically preventing any use being made of the shoulder-joint.

2. Active movement is usually possible, although weak, but in a certain number

of cases is quite absent. Active movement is the standard of success, and unless active movement is good, and lateral mobility slight, there is no doubt that an elbow ankylosed in good position gives the patient a great deal more serviceable limb.

FIG. 266.—*Case* 10. Pensr. D. Limited excision. Useful joint.

The resulting joint is also greatly dependent upon the immediate post-operative treatment. The forearm must be supported efficiently to prevent the fibrous union from becoming stretched, and it is noteworthy that in *Cases* 1 and 2, where no active movement was possible six months and three months respectively after operation, no attention had been paid to the support of the forearm, and in some of the other cases the weight of the forearm had been taken by the young fibrous tissue far too soon.

This stretching of the fibrous union also accounts for a condition of overriding of the bones when voluntary flexion returns. The humerus overrides the forearm bones on their outer side, and in flexion the arm is apparently shortened before the movement of flexion occurs by contraction of the long flexors of the forearm. This "taking in of the slack of the joint" is well seen in *Figs.* 260 and 261. This patient had a lucky formation of a periosteal bone spur on the inner side of the humerus, and this acted as a pivot which gave support to the ulna in flexion. He had a very useful arm.

The Treatment of the Flail Joint.—This is the problem that most concerns the surgeon at the orthopædic hospital. The joint has become flail as a result of: (1) Too wide a removal of bone; (2) Subsequent stretching of the soft tissues.

The former cannot be remedied (those extensive enough for bone-grafting to be considered are classed as flail limbs, not flail joints); but the result of stretching of the soft tissues may be considerably helped by:—

A. Support.—In all cases the weight of the forearm must be taken from the soft tissues joining the humerus and forearm. This can be done by a simple forearm sling bringing the wrist well up towards the neck, or the arm may be put up in full flexion in plaster-of-Paris for a month or six weeks, to allow contraction of the stretched soft tissues. The actual improvement possible, even after there has been stretching, is seen in *Figs.* 263 and 264, where a 2½-inch gap was reduced to half an inch by this means alone.

B. Massage, Electricity, and Hydrotherapy, to improve the tone of the stretched tissues.

C. Operation.—In *Cases* 5 and 6 in this series an attempt was made to reef in the excess of new fibrous tissue that was allowing the excessive play at the elbow. A simple capsulorrhaphy through a posterior incision

FIG. 267.—*Case* 11. Edr. E. Ankylosis.

was performed, and the new 'capsule' reefed posteriorly and at both sides. There was some improvement in the degree of lateral mobility in each case, but one of the patients (*Case* 6, *Fig.* 265) suffered some subsequent inconvenience from a 'grating' of the two bone surfaces thus brought closer together. I do not think this would have occurred had the ends of the bone at the primary excision been covered by muscle-fascia flaps.

D. Mechanical Treatment.—The functional report on the above cases was made before any mechanical support was provided. The provision of a light aluminium support consisting of two lateral pieces hinged at the elbow-joint and restraining lateral mobility, whilst allowing flexion and extension, considerably aids voluntary movement.

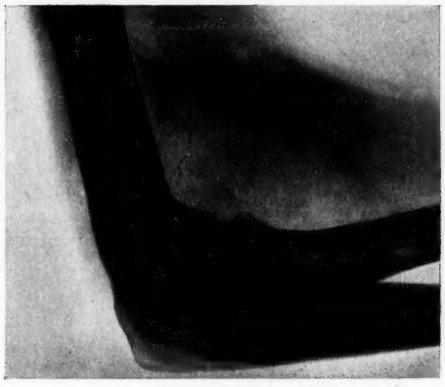


FIG. 268.—*Case* 12. Pte. P. Showing ankylosis before operation.

FIG. 269.—*Case* 12. Pte. P. Showing extension obtained after limited arthroplasty.

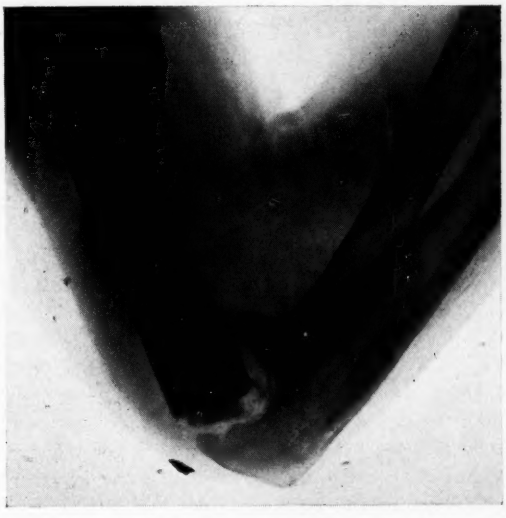


FIG. 270.—*Case* 12. Pte. P. Showing flexion obtained after limited arthroplasty.

Comparison of Results of Primary Excision with a Case of Arthroplasty for Ankylosis.—In comparison with the above series, I would quote the following case

of arthroplasty of the elbow performed for ankylosis after a gunshot wound. *Case* 12 (*Figs.* 268, 269, 270). This patient had very little comminution of the bone, but a septic arthritis, and injury to both median and ulnar nerves. Nerve repair was performed six months after the wound, and a partial arthroplasty five months later. The arthroplasty consisted in removing the external condyle of the humerus piecemeal, and the articular surface of the head of the radius, then dislocating the joint outwards, and sawing the humerus off just below the epicondyles. This method allows the bone to be removed through a small incision, with no injury to the triceps tendons, and only a little weakening of the external aspect of the joint. The sigmoid cavity of the ulna was preserved, and the lower end of the humerus rounded off and covered by a flap of muscle-fascia from the extensor origin. The joint was kept in full flexion for three weeks without any attempt at movement. At the end of this time there were 40 degrees passive movement without pain, and six weeks after the operation there is 75 degrees voluntary movement, painless, and only 5 degrees lateral mobility internally and none externally.

CONCLUSIONS.

1. Extensive primary excision must result in a flail joint.
2. Limited excision is satisfactory.
3. If the bone is comminuted, muscle-fascia flap should be carried in to cover comminuted bone as is done in arthroplasty.
4. Post-operative support of forearm is essential.
5. Rest is more important than early movement.
6. Capsulorrhaphy in certain chosen cases of flail elbow does good.

REFERENCES.

[1] Col. Mansell Moullin, *Brit. Med. Jour.*, 1917, Nov. 3.
[2] Major Jocelyn Swan, *Brit. Med. Jour.*, 1918, Jan. 26.
[3] Capt. Moir Sheppard, *Brit. Med. Jour.*, 1918, Feb. 2.

THE STRUCTURE, FORMS, AND CONDITIONS OF THE ENDS OF DIVIDED NERVES:

WITH A NOTE ON REGENERATION NEUROMATA.

By Major EDRED M. CORNER, R.A.M.C. (T.)

(A Report to the Medical Research Committee.)

The first steps in any undertaking should be to prepare the ground carefully, in order to form a sure foundation for subsequent work which may be built upon it. This is the object of the present preliminary report on the nerve endings in amputation stumps, and upon it the writer hopes to build a strong pathological and clinical superstructure.

When a nerve trunk is divided, it retracts—provided it has not previously been torn from its bed, as may easily be done. Of the two kinds of tissue thus divided: (1) The divided nerve fibres commence to degenerate and afterwards regenerate, undergoing two changes; and (2) The divided connective tissue (the endoneurium, perineurium, and epineurium) commences at once to repair, and, undergoing but one change, gets a considerable start as compared with the nerves. Consequently, in the early stages the end bulbs of a divided nerve consist very largely of fibrous tissue. Into that bulb of scar tissue the nerve fibres grow. The central part of the nerve bulb is formed from the repairing inner coats of the nerve (the endoneurium and the perineurium). Its outer and circumferential parts are largely formed from the outer coat (the epineurium). This connective-tissue bulb has partly ceased to contract by the time the nerve fibres grow into it, by reason of its early start, and it offers a substantial buffer to the regenerating nerve. The varying densities produced by the growth and contraction of this fibrous tissue give ever-varying patterns of the nerve fibres in it: some have been observed in serial sections to be completely turned round, apparently by the action of contracting fibrous tissue, into a U-shape (*Fig* 271); some of the loops hook over each other. Hence the ever-differing irregular arrangements of the nerve fibres within the bulb—the internal plexiform neuroma, as Professor Marinesco of Bucharest termed it.*

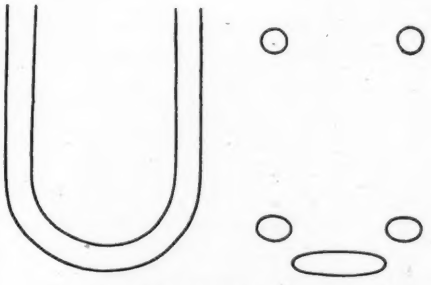


FIG. 271.—To illustrate how a nerve fibre growing alongside a bundle of scar tissue can be made to turn completely round and grow backward, forming a U. Also its appearance on section at the different levels.

The ascending neuritis—as evidenced by the increased amount of connective tissue between the nerve bundles, and its added vascularity—travels up between the fibres in the central part of the nerve trunk. In the nerve end there is little or no separation of the nerve fibres near the periphery. The bundles of central fibres become more tortuous and further separated from each other as they approach the bulb (*Fig.* 272). On reaching the bulb, they undergo more twisting, forming a well-marked 'zone of twisting.' Beyond this the nerve bundles come closer together, interlacing with the centrally-bent peripheral fibres to form a dense tissue in the central parts of the bulb,

* *Proc. Roy. Soc. Med.*, 1918, xi, p. 5.

the 'zone of lacing.' This tissue gives the bulb its hardness, and the small amount of closely-packed connective tissue between the bundles of nerve filaments allows of only a very little swelling before causing pressure on nerves and a painful sensation. This, then, is a situation where very little inflammation may cause much pain. The dense network produced by the interlacing and tortuosity of the central and peripheral nerve fibres becomes looser as the apex of the bulb is approached. Finally, the apex is penetrated by the terminal perforating fibres.

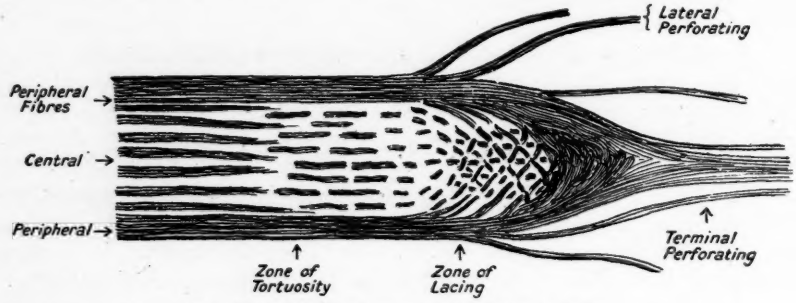


FIG. 272.—Scheme of nerve conformation in bulb.

On making a section of the bulb, the network of nerves, the 'zone of lacing,' protrudes in an irregularly convex form, the pressure on one side being relieved by the section.

The part of the end bulb formed largely from the inner and middle coats, the endoneurium and the perineurium—the core of the bulb—is not always central and symmetrical, and gives different shapes to the bulbs by its variations. Over this central mass and in continuity with it is the epineural cap of fibrous tissue. It is well to visualize this cap of connective tissue, which has begun to contract before the regeneration nerve fibres have

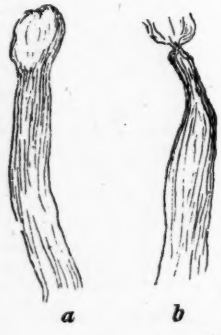


FIG. 273.—*a*, Nerve bulb; *b*, Nerve pencil; drawn from actual specimens removed by Major Chapple. The nerve which formed the bulb was cut across. The nerve which formed the pencil was amputated by the sleeve method.

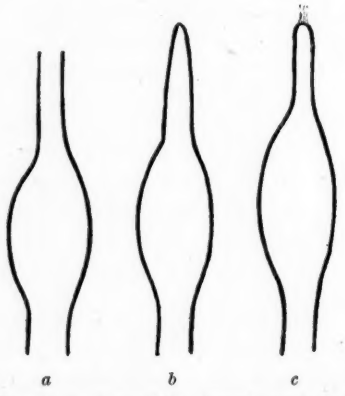


FIG. 274.—*a*, Nerve bulb, formed mostly from the endoneurium and perineurium after nerve division by crushing. *b*, The above with a nerve pencil, formed by the amputation of the nerve with a sleeve of epineurium distal to the crushing. *c*, The regeneration from the point of the pencil end.

grown into it. Unfortunately a little contraction on an inflamed nerve fibre causes much pain. In the nerve pencils, as contrasted with the bulbs, the epineurium is preserved as a sleeve, and does not participate directly in the formation of the nerve endings.

A *nerve bulb* is formed by dividing the epineurium, perineurium, and endoneurium at the same level. (*Figs.* 273 *a*, 274 *a*.)

A *nerve pencil* is formed by dividing the perineurium and endoneurium at one level and the epineurium lower down, so as to cover the stump with a sleeve of epineurium. (*Figs.* 273 *b*, 274 *b*.)

A *nerve spindle* is formed by partially dividing both the endoneurium and perineurium and leaving the epineurium intact. (*Fig.* 274 *c.*)

The several forms of bulb are fashioned by the varying parts which the different nerve coats take in their formation. When the fibrous core to the cap just referred to is in the centre of the bulb, the peripheral nerve fibres are distributed symmetrically around it; but if it is eccentric, the fibres situated on the periphery of the nerve trunk pass it by asymmetrically, more on one side than on the other, and being curved round its surface, as directed by the fibrous tissue of the cap, some interlace and others escape at the apex of the bulb. Thus, the end bulb ceases to be an end of the nerve. Regenerating fibres pass it by; some escape by the side of the bulb, and some from the apex. The more eccentric the core, the more peripheral fibres will be on one side or the other.

Practically, the end bulb is not an end of the nerve fibres: these can grow into any adhesion or along any scaffolding of connective tissue. The adhesion of a nerve bulb to a muscle is a very frequent event in painful conditions, and the scar tissue of the adhesion offers a scaffolding for the nerve fibre to grow along and infiltrate the muscle, every contraction of which must jar the bulb. This has been demonstrated, and in addition Professor Marinesco has shown new nerve fibres from the median nerve infiltrating the tendon fibres of the flexor sublimis digitorum. In these cases the adhesions are almost always lateral to the bulb, being particularly frequent on that side of the bulb where there are most peripheral fibres. Of all the nerves of the body, adhesions to muscles are most frequently found on the stump of the sciatic.

It is chiefly the fibres which escape from the sides of the bulb that infiltrate the surrounding structures through the adhesions to the latter. From the apex of the bulb fibres strain out, and, like a river, seem to follow the line of least resistance. Usually this is by the old course of the nerve, or else along the vessels. Thus, the internal saphenous nerve from Hunter's canal on the front of the thigh may communicate with a regenerating sciatic behind via the course of the vessels.

Regeneration Neuromata.—Should the flowing growth of the regenerating fibres meet an obstruction, they bank up, as a stream forms a lake, so causing a tumour of new growth, a regeneration neuroma. The regeneration neuromata are far more often found on small nerves of devious course than on large nerves which run a plain easy path. On small nerves they are multiple and coursal, along the nerve's course, whilst on large nerves they are simple and terminal. These regeneration neuromata have been found most often—and multiple, three or four—on the internal saphenous nerve; less often and less in numbers on the small sciatic nerve. Never have they been found multiple in the arm, though there is no apparent reason why they should not so exist; perhaps the true reason is that the arm in general produces simple and straightforward problems and conditions as compared with the leg. Regeneration neuromata grow mainly in the leg; they may be multiple; as single tumours they form the terminations of all large nerve trunks formed by regeneration, and consist of a large and varying amount of fibrous tissue and a small and varying amount of nervous tissue.

Nerve-bulb Pain.—What makes the nerve ends painful? There are several theories. The first has been most recently and loudly advocated by Captain Sydney Cone in a long and learned paper.* After much labour and research he has found and elaborated a specific stain for neurokeratin. From a study of the results he has concluded that "three-fourths of each (painful bulb) consists of young nerve fibres," and that "they cause pain apparently by their excessive proliferation against resistance" of scar tissue. One can follow this theory quite well, and easily understand that, within reason, the older the bulb the more numerous the nerves within it. But as a clinical explanation the theory fails, because after section every nerve end is tender for four to six weeks. In normal cases the tenderness disappears just at the time when the intrabulbous nerve pressure

* *British Journal of Surgery*, 1918, v, No. 20, p. 524.

from the growth of young nerves should be coming into operation. In such a common and normal case the theory of neural-growth causation of nerve-end pain fails.

Perhaps the most popular theory of nerve-bulb pain was that it was due to constriction and compression from the contraction of the scar tissue in and around the bulb. Many examples of this condition are to be found in studying the structure of nerve bulbs, both in those which clinically are painful and in those which are painless. The following may be cited :—

1. When a microscopic section is made of a nerve which has not been hardened as it lay stretched out, the fibres are seen to be waved. In the same section there are often both waved and straight fibres, showing that some are held out very taut—most probably by the fibrous tissue between the nerve bundles—whilst others are not so held. There is evidence of tight hold, if not of strangulation.

2. The interior of a nerve bulb is filled with a network of nerve fibres, loops of which knot with other loops, the knots so formed being more or less tightly drawn. A section of a painful neuroma showed this, and also the tortuosity of the fibres in the bulb, its

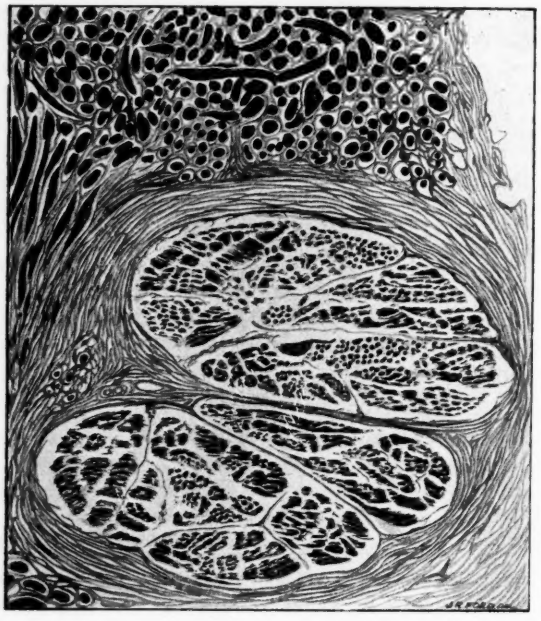


FIG. 275.—Showing nerve fibres crushed by the contraction of the surrounding fibrous tissue. Nerve fibres without a capsule, and uncrushed, are shown at the upper part of the section. (× 30.)

great vascularity, and the large amount of œdematous fibrous tissue within it. The nerve bundles were very twisted.

3. The fibrous capsule of the bulb is not often contracted so as to be observable with the naked eye, like that of a hobnailed liver. Occasionally a bulb is seen to be wrinkled, with fibrous downgrowths into it. More frequently the contractions can only be seen with a microscope.

4. In another section there was a strangulated island of nerve tissue, the strangulation being suggested by the irregularity of the neural waves in the pinched 'island.' They were like those on boiling fluids.

5. A section of a sciatic nerve showed a very remarkable state of affairs. Growing down from the capsule of the bulb was a band of fibrous tissue, which divided, embracing many nerves in a kind of alveolar arrangement. By contraction of the walls the contained nerves were crushed. In the drawing (*Fig.* 275), crushed and uncrushed fibres may be compared.

6. A section of a strangulated nerve showed œdema of the interfascicular connective tissue, starting from the point at which the fibres were constricted. Œdema was present in all parts distal to where the lymphatic flow was impeded.

7. A section from another case also showed strangulation and twisting of an œdematous nerve bundle.

8. Another section was interesting as demonstrating a slight strangulation of two nerve bundles by a bridge of scar tissue, which only pressed sufficiently to damp off the size of the waving as the bundles passed under it.

9. In another section the nerve bulb showed a strangulated and twisted nerve bundle, with increased amount and vascularity of the connective tissue.

10. A section showed a strangulated nerve island, with increased size and irregularity of the waving. There was also a band over a nerve bundle, which was constricted at that point, the nerve-waving being damped off.

11. Another section showed very clearly a strangulated and twisted nerve bundle, with increased vascularity and quantity of interfascicular connective tissue.

12. Another section showed the presence of a large collar of scar tissue which by it contraction had bitten deeply into a nerve bundle, causing its severe strangulation.

13. In another section there was strangulation of a severely constricted nerve bundle.

Doubtless these two factors, the raising of the intrabulbar pressure by neural growth and the contraction of the fibrous tissue, have some significance. They can be found, however, when there is no complaint of pain, and consequently cannot be regarded as giving a pathological explanation of this clinical symptom. Professor Marinesco and I have shown* that the true explanation is to be found in the raised intrabulbar pressure and the irritation of an infective inflammation which is the characteristic of painful stumps, and that this is favoured by the presence of foreign bodies, reaching the nerve bulbs by direct extension if the nerve has not been cut short, or indirectly by the lymph stream if it has. If these foci of inflammation should be in the 'zone of lacing' of a nerve bulb, pain is quickly and easily caused, as there is little room between the nerve bundles for swelling. A swollen nerve is more susceptible to twisting, pressure, and strangulation, and more painful therefrom. Doubtless, therefore, increased intrabulbar pressure accounts in some degree for the pain of nerve endings; but the pressure and irritation of infective inflammation is the prime factor which produces the pain. As the presence and extent of this factor has been frequently demonstrated by me elsewhere,* no more need be said here. In this report I wish to consider the various shapes of nerve bulbs, their methods of production, and the zones of contraction around them, as these have not been detailed previously.

Nerve bulbs take four shapes; three of these are fairly well known, but one has been noted only recently, and is as yet imperfectly recognized. They are (1) The nerve bulb; (2) The nerve pencil; (3) The nerve spindle; and (4) The nerve drop.

1. The first of these is the best known by far, and is produced by merely cutting across the nerve transversely or obliquely. Roughly, it is made up by the coats of the nerve as follows: Near the regenerating fibres is a mass of scar tissue resulting from the repair of the endoneurium; outside this is a cap of perineurium; and most external is a cap of epineurium. Why has the trouble been taken to enumerate these facts? The answer is that only in the bulb and close to it is a regenerating nerve fibre in danger of compression. Once let the fibre penetrate beyond the cap of scar tissue furnished by the nerve coats, and it will have grown into a region where the scar tissue has largely ceased to contract and now merely acts as scaffolding along which the regenerating nerves grow. Only near the bulb does the regenerating nerve fibre run the risk of being compressed. Once beyond,

---

* In a lecture at the Royal Society of Medicine in April, 1918, and later, I have demonstrated to the Surgical, Neurological, and Electro-therapeutic Sections of the Royal Society of Medicine in May at the Welsh Metropolitan War Hospital, Cardiff, in April; and at St. Thomas's Hospital in May.—*Proc. Roy. Soc. Med.*, 1918, June; *Brit. Med. Jour.*, 1918, June.

it is safe, except for accidents, such as where it is strangulated and adherent to bone, as in a Syme's amputation.

2. The nerve pencil is a very definite structure which is produced by amputating the nerve so as to cover the stump with a sleeve of epineurium. This method only fails in its technique. Epineural flaps are sometimes 'holey,' and indeed inefficacious, in their fashioning. They are condemned by Captain G. M. Huggins in his excellent little book on amputation stumps.* Captain Huggins has had an unrivalled experience of amputation stumps at Brighton, added to an extended surgical experience at St. Thomas's Hospital, and later in South Africa. His opinion is therefore valuable. But undoubtedly the zone of certain compression around the tip of the nerve pencil is smaller than that around the nerve bulb (*Fig.* 276). A nerve pencil can be made by crushing the nerve and transfixing and ligating the crushed part with fine catgut. This method I have often used, and it is more certain than any epineural sleeve; but experiments often reveal that a number of the fibres were not divided by the crushing, the filaments only being compressed. The epineurium (outer coat) was rarely divided except by Kocher's crushing forceps. The best instrument I found was the smooth appendix clamp made for me in 1903 by Messrs. Allen & Hanburys.

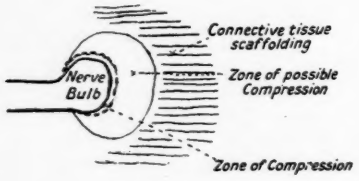


FIG. 276.—Diagram to illustrate the zones of nerve-fibre compression by the cicatrization of the scars next to the nerve end. The innermost zone, mostly derived from the endoneurium, is that of certain compression. The middle zone, mostly derived from the perineurium, is that of possible compression. The outer zone, mostly derived from the epineurium, contains scar tissue which has ceased to contract, and its fibres act as scaffolding to the growing nerve shoots.

3. The nerve spindle is produced by crushing the nerve, the object being to divide the nerve fibres and not the connective-tissue coats. This has been accompanied by varying success. The vasa nervorum certainly did not bleed. But the method was discarded because the crushing caused a certain amount of epineuritis around the nerve, with subsequent pain, adhesions, and a generally unsatisfactory condition.

4. One of the most successful methods of nerve amputation for curing pain is by nerve anastomosis, but the method is too laborious for ordinary use. Its results are excellent, and seem to depend on the thoroughness with which the steps of the operation are done. It has been modified and made more generally useful by the L-operation. This method gives rise to a nerve drop; but it is too recent for its results to be really known yet. Its bulb is certainly very like the ordinary end bulb, but longer.

The usual method in my practice is that of the 'swing door.' The nerve is gently drawn down, divided by two cuts (one from either side), and then allowed to retract, the backward movement closing the flaps like swing doors. It forms a bulb like the ordinary bulb, but the nerve is shortened and its end closed cleanly and without stitches or manipulation.

Lastly, there is the nerve triangle to be mentioned. It is found particularly in the musculospiral and posterior tibial nerves, and is produced by the nerve becoming adherent to bone, its end being unable to expand to form a bulb. The result is a very flattened nerve end, often of triangular shape, as when a nerve becomes attached to a bony spur.

The zones of compression about a nerve end are clinically not much affected by the shape and fashion of the bulb. The cause of the pain is not compression of the nerve trunk: that only accentuates the pain already created by the foci of inflammation within the bulb, and is in no obvious way affected by the shape of the nerve end.

---

* Frowde, Hodder & Stoughton.

INJURIES OF THE PERIPHERAL NERVES FROM THE SURGICAL STANDPOINT.

By Major H. S. SOUTTAR, R.A.M.C., and Captain E. W. TWINING, R.A.M.C.

Injuries of the peripheral nerves present one of the most difficult problems which have arisen in the surgery of the war. The curious inquiry of a few specialists has suddenly become a question of urgent importance, the answer to which it is hard to find. Not only must the general surgeon undertake operations with the technique of which he is not familiar: the surgeon who has had previous experience of nerve injuries in civil life finds himself confronted by problems which tax his ingenuity to the utmost, many of which are still unsolved. It has therefore appeared to us that the careful consideration of cases which have come under our notice might be of some value at the present time. We propose to give an account of these cases, of the observations which we have made, and of the deductions which we consider may be drawn from them. By presenting the whole of our material in an abbreviated form, we hope to make it possible for any who may care to study it to decide for themselves whether or not our deductions are justified, and to give to each of these its proper value. We shall entirely avoid speculation, and shall limit ourselves stringently to what we have ourselves observed.

We are confronted at the outset by the difficulty of keeping patients under observation for a sufficient time. Some cases, however, we have been able to follow through to their recovery, and by adding a brief Summary to most of the case histories in *Appendix B*, we have been able to place in their true perspective our observations on those cases whose record is less complete. This seemed to us better than to discard cases of great interest—many of them those from which we have learnt the most.

This paper is founded on the series of cases of nerve injury which have passed through this hospital in the last two years. We have excluded cases of a trivial or transient nature, and those which were transferred to other hospitals before adequate observation could be made. The cases were under the care of the various medical officers of the hospital, to whom we would record our thanks, and to whose skill the recovery of many of the patients was due. For notes on some of the earlier cases we are indebted to Colonel Miller, A.M.S., of whose admirable records we have made full use.

Our observations were made on 128 cases, which may be grouped as follows:—

Nerve	Operation	No Operation	Total
Ulnar	18	10	28
Median	7	6	13
Median and ulnar	8	2	10
Musculospiral	8	13	21
Posterior interosseous ..	3	3	6
Musculocutaneous	1	—	1
Brachial plexus	9	2	11
Internal popliteal ..	2	2	4
External ,, ...	7	9	16
Internal & external popliteal	7	5	12
Lumbar plexus	—	1	1
Facial	—	6	6
Total cases ..	70	59	129

METHOD OF EXAMINATION.

In examining our cases a definite routine has been followed, and the examination itself has been reduced to as simple a form as possible. A complete investigation of every case would have furnished work for an army of neurologists, without practical results of commensurate value. By very simple methods it is possible to discover

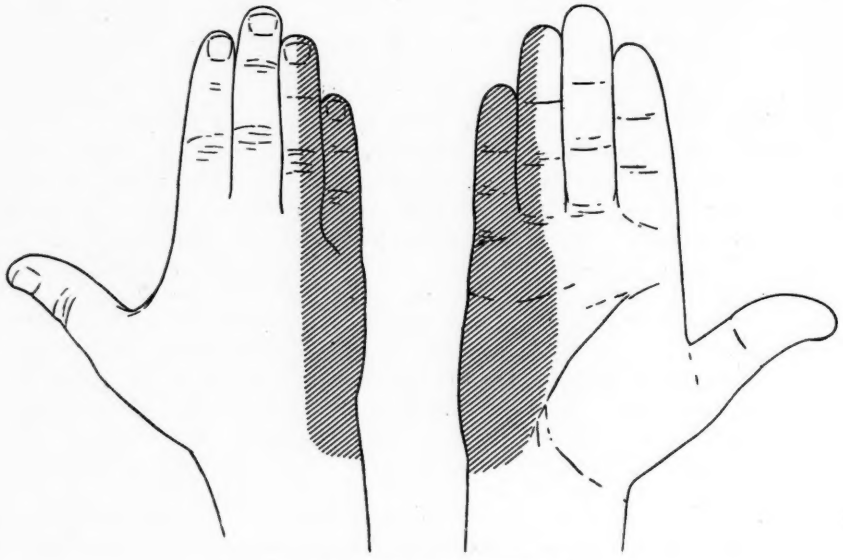


FIG. 277.—Ulnar area of anæsthesia.

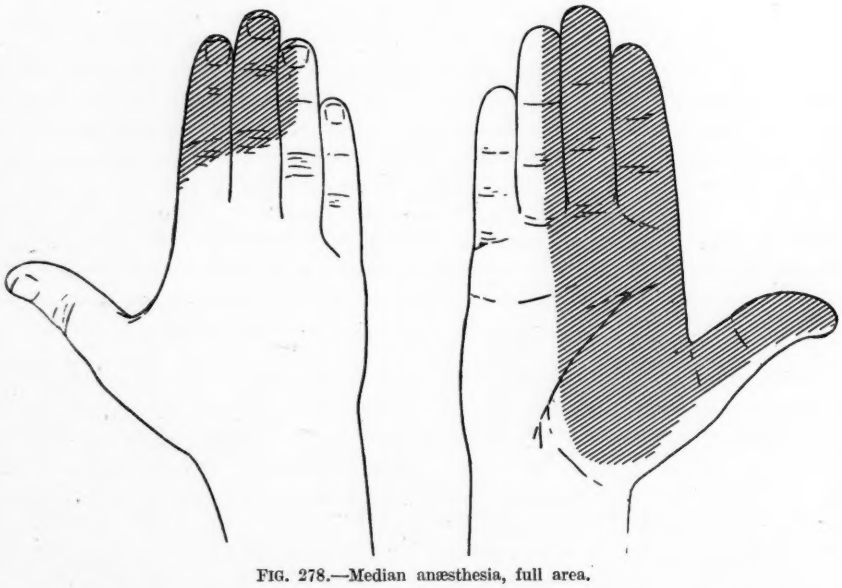


FIG. 278.—Median anæsthesia, full area.

the site of injury, and to estimate its degree. By similar examinations at intervals of a few weeks we can follow the course of a case and form some idea as to its prognosis. By the time wounds are sufficiently sound to allow of operative procedures, we shall be in a position to decide on the advisability of the latter, and in

most cases we shall be able to state whether neurolysis or actual resection is required. We would lay stress on the great value of continuous records even of the simplest nature, as against a single investigation even of the most elaborate completeness.

Sensory.—Cutaneous sensation is tested with a soft camel-hair brush and a pin. The former, if lightly used, furnishes a convenient and rapid means of mapping out epicritic sensation, but the charts of protopathic loss obtained by pin-prick are more reliable, and, with the rather insensitive skin of the soldier, are more readily obtained. In general the difference between the areas is negligible, the protopathic loss being the smaller except in very high lesions of the nerves. It is essential that no confusion should be caused by deep sensation, which a brush may arouse by moving the hairs whose roots are supplied from this source, and a pin through pressure. Deep sense is carried up by tendons and motor branches along routes entirely different from those which serve other cutaneous impulses; it often remains intact in complete lesions of the main trunks of supply, a fact which is responsible for many of the cases of 'early recovery' of which one reads. The areas of sensory loss corresponding to the principal nerves are shown in the charts (*Figs.* 277–280). It must, however, be noted that these are by no means constant, and that they do not always correspond with the areas described in anatomical text-books. We are, in fact, dealing with function, and not with the gross distribution of fibres. Thus, the large area of anatomical radial supply is in striking contrast to the minute area of sensory loss which is found in complete lesions of this nerve. The fact is that a large part of the skin has a multiple supply, and it is only in that part which is exclusively supplied by the affected nerve that sensory loss is seen. In irritative lesions of nerves, on the other hand, the whole anatomical area of supply is affected, and in such cases this area can be mapped out as a region of extreme sensitivity.

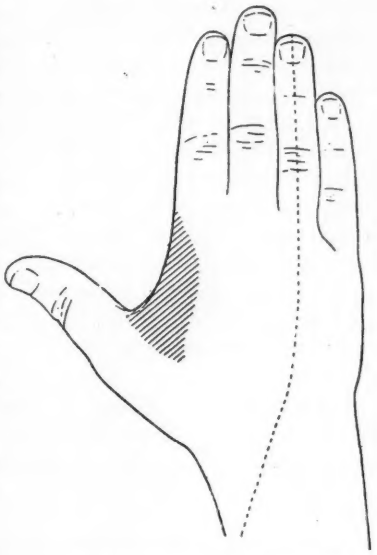


FIG. 279.—Musculospiral anæsthesia, usual area. Dotted line shows complete area.

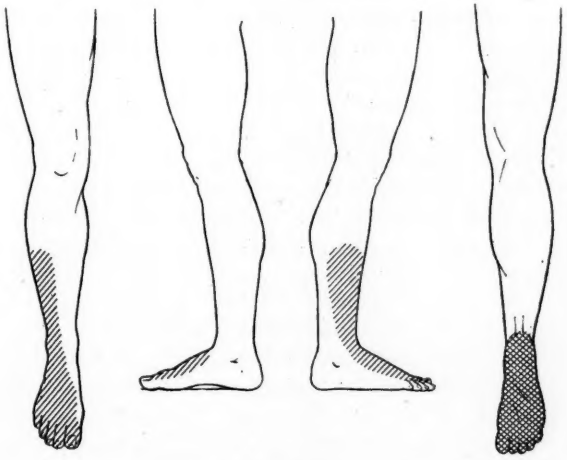


FIG. 230.—Sciatic areas of anæsthesia.

Trophic.—Trophic changes are rarely marked except in the case of partial and irritative lesions. The skin may be dry and covered with a branny desquamation, or glossy and glistening with minute beads of sweat, or it may be sodden and offensive and covered with a thick layer of cutaneous débris. These changes appear to be largely due to want of use of the limb, for when the nerve has been freed or sutured, and the limb efficiently treated by massage and baths, they rapidly disappear, long before any recovery of nerve fibres is possible. In our experience trophic changes in limbs under full treatment are insignificant.

Motor.—The motor results of a nerve lesion are by no means as easy to demonstrate as might at first appear. An accurate knowledge of the nerve-supply of the

various muscles, and of the exact movements which each produces, is essential. With each nerve there are certain critical movements for which we must look, and there are certain errors which we must avoid.

The musculospiral produces extension of the wrist and of the proximal joints of the fingers. Extension of the two interphalangeal joints of the fingers is produced by the lumbricals and interossei (median and ulnar), and abduction of the thumb by the abductor pollicis brevis (median), which in some cases sends a slip to the dorsal expansion on the thumb, and can thus produce extension of the terminal phalanx.

The characteristic movements produced by the median nerve are flexion of the index and of the thumb, and opposition of the thumb. In the last movement rotation of the metacarpal is the essential feature, the thumb nail turning to face the observer looking at the palm. In adduction of the thumb produced by the adductor pollicis (ulnar), this rotation does not occur.

Only the ulnar can produce complete flexion of the little finger and ulnar flexion of the wrist. But the chief feature of an ulnar lesion is the wasting of the small muscles of the hand, specially noticeable in the first interosseous space. The little and ring fingers assume a slightly clawed position, but the complete claw-hand is only seen in combined lesions of the median and ulnar, where all the lumbricals are paralysed.

In complete lesions of the median and ulnar, flexion of the wrist can still be performed, and is at first sight a very perplexing phenomenon. It is carried out by the short extensors of the thumb, which pass slightly to the front of the wrist-joint.

Lesions of the brachial plexus may give rise to paralyses of great complexity, but they can often be easily resolved if it is remembered that section of the fifth cervical root produces paralysis of the deltoid, biceps, brachialis anticus, and supinator longus, whilst section of the first dorsal root produces paralysis of all the small muscles of the hand, which becomes completely clawed.

In the leg, movements are simpler, and loss thereof is more easily referred to its source. The external popliteal elevates and everts the foot, the internal popliteal depresses it. But it should be noted that quite powerful flexion of the ankle can be produced by the peronei, accompanied, however, by very marked eversion. Even in high lesions of the sciatic, paralysis of the hamstrings is rare, and in none of our series has it been complete. The lumbar plexus is so placed that injuries to it are usually fatal; only one instance occurs in our series.

Electrical.—The tests which we use for diagnosis are of the simplest nature. Two small spherical pads are used, connected with a variable galvanic or faradic supply with a metronome interrupter in the circuit. Ten days after a complete nerve lesion the reaction of degeneration can be obtained, with the slow, undulatory contraction to galvanism and the absence of any reaction to faradism. But in our experience paralysed muscles vary greatly in the rapidity of their contraction, some reacting quite briskly when the nerve is known to be entirely severed. A more constant phenomenon is the slow relaxation which occurs, so slow that a quick metronome interrupter may have had time to send a fresh stimulus before relaxation from the first contraction is complete. The electrical reactions are of importance in that they enable us to eliminate the possibility of a functional paralysis, which may perhaps have followed on a real but trivial injury to a nerve. In such a case the muscles will always respond readily to a faradic current.

CARE OF THE LIMB.

The lesion diagnosed, the next thing is to make arrangements for the care of the limb. It is essential to remember that upon the amount of trouble and skill expended on the limb before operation the ultimate result will largely depend. Muscles must be kept relaxed and in good condition, tendons must not be allowed to become adherent, nor joints to become stiff. It is not sufficiently realized that it is quite

possible to keep a paralyzed limb in such perfect condition that only an expert can detect from its appearance that any abnormality is present. The so-called trophic changes are largely the results of neglect, not of any inevitable pathology.

Massage.—This should be started at the earliest possible moment, and splints should be so arranged that as much as possible of the limb can be reached. A gentle exercise for the muscles is thus obtained, the lymphatic circulation is stimulated, and the skin is kept in a healthy state. Very special attention should be paid to the fingers and to the preservation of their complete mobility, particularly at the metacarpo-phalangeal joints. A few weeks' neglect may result in a stiffness of the hand from which recovery may be impossible.

Mechanical Treatment.—As repair proceeds, it is possible to adopt more vigorous methods, and many ingenious appliances have been devised for persuading the patient to use his limb, for it must always be remembered that this is the ultimate goal. In those of the Zander type a pendulum or flywheel is always included, the inertia of which tends to carry each movement a little further. Others provide graduated resistance to various movements, requiring more volitional effort on the part of the individual. We have a large department equipped with both types, and the men pass from one machine to another, obtaining variety of exercise and of interest.

Whirlpool Baths.—The whirlpool bath is a form of treatment which we owe to the war, and we are becoming every day more convinced of its value. As our equipment presents some novel features, it may be worth while to describe it in some little detail. It is specially well suited to the requirements of a hutted hospital, where the water-supply is limited, and where a large supply of hot water under pressure is unobtainable.

Our baths are so arranged that heated water from a tank is driven by a centrifugal pump through the baths, and returns to the tank by gravity. The temperature of the water is maintained by a small gas-heater through a separate circulation. This system is extremely economical, both in construction and in use, for only about 500 gallons of water are required to operate our twenty baths, and the loss of heat is so small that only a bye-pass is used for the gas after the water has once been heated. As 3000 gallons of water per hour are driven through the baths, the economy of water and of heat will be obvious. The water is changed once a day, and this appears to be quite sufficient. No inconvenience has arisen from the repeated use of the same water. One great advantage of the system is that it is self-contained, and requires only a small water-supply, a small source of heat, and a small source of energy. It can be controlled by an orderly of average intelligence, and it is almost impossible to put it out of order.

The cost of our original installation of eleven baths was about £200, and the cost of maintaining these was about 1s. per hour. In our present installation we have introduced an air-compressor, a somewhat expensive addition, though it adds considerably to the possibilities of treatment. The total cost of the apparatus, with twenty baths, as it at present stands would be about £500. It is our routine practice to give twenty minutes in a bath, followed immediately by ten minutes' massage. The chief effects of the bath are a great increase in vascularity and a remarkable softening of the tissues, with the result that massage is greatly facilitated and much time and labour are saved. The freedom of movement of joints and muscles which follows immersion in a bath is very striking. In a few days the skin, from being glazed and atrophic, becomes soft and thick, the muscles become supple and elastic, and the mobility of the joints is increased. Even in the case of extensive nerve lesions the appearance of the limb becomes almost normal, and the familiar trophic changes are almost entirely absent.

We regard the whirlpool bath as the most powerful curative physical method at present at our disposal. It facilitates other methods, softening the limb for massage, and increasing its conductivity for electricity; it reduces pain; and it produces in the patient a feeling of well-being in the limb which stimulates him to those voluntary exertions without which no complete recovery can be obtained. A very important feature of the

treatment is the great economy in massage effected. The duration of massage has been reduced from 30 to 10 minutes, the actual process is easier and less laborious, while the results are in every way superior to those which we could previously obtain.

Electrical Treatment.—There has been a considerable development in electrical methods of treatment to meet the requirements of war surgery. Many ingenious appliances have been evolved, of which we make full use, but it is only possible to mention briefly a few of these in the present paper. In the treatment of muscles whose nerve-supply is completely severed, the interrupted galvanic current still holds the first place, and will form the basis of any routine. It may be applied in several ways. We usually place a large pad connected with the positive pole around the proximal part of the limb, and a small pad is moved from point to point over the distal portions of the muscles till satisfactory contractions of each are obtained. Interruptions are produced by a metronome, and a rheostat controls the potential. A general stimulation of the muscles may be obtained without the use of any interrupter, the variations of current produced by sliding the small pad from point to point being sufficient to evoke contractions. It is important in any case that the current should pass longitudinally along the muscle fibres, and in the case of a paralyzed muscle the best contractions will usually be obtained by placing the small pad in the region of the tendon of insertion. Care should be taken to avoid fatigue, and when a muscle shows signs of flagging, another should be selected for stimulation.

In some cases, however, this method is too painful, especially where the lesion of the nerve is incomplete. In such cases we have obtained excellent results from the slow galvanic oscillation given by a Wilson modulator. The action of this machine depends upon the remarkable circumstance that a paralyzed muscle may be made to respond to a galvanic oscillation too slow to stimulate a normal muscle. It is thus possible to obtain dorsiflexion of the wrist in a case of complete musculospiral paralysis without corresponding contraction of the flexor muscles.

As the nerve recovers and the faradic response returns, it is important that full use should be made of the more complete and lasting contraction which this form of stimulus evokes. It may be applied through pads similar to those just mentioned, or one of these may be replaced by a small roller. In other cases the limb is immersed in a bath, through the length of which a faradic or sinusoidal current flows, varied by some form of interrupter, sudden or gradual.

The high degree of skill required for effective electrical treatment is not always appreciated, and we would lay stress on the importance of thorough training in those who carry it out. The actual operator must have some knowledge of the action of the various currents used, of the anatomy of the muscles, and of the movements produced by their contraction. And her work must be supervised by an expert fully trained in all these matters. The unskilled use of a coil or a battery cannot be too strongly deprecated. It can only cause disappointment, and may produce serious damage.

Splints.—In the intervals between treatment, the limb must be kept warm and its insensitive portions protected from injury. Light splints must be carefully applied in such a manner that, whilst they keep paralyzed muscles intact and prevent development of contractures, they interfere as little as possible with the use of the limb. We consider however, that the statements which have been made as to the dangers of stretching a paralyzed muscle have been greatly exaggerated. It is certainly essential that the muscles should be kept relaxed during the greater part of the day and night. When, however, the splints are removed by the masseuse, it is our custom to flex and extend the joints over their full range of movement, and we have never seen ill results follow. We should like to enter a word of warning against the grotesque positions into which limbs are sometimes forced on the plea of obtaining more complete muscular relaxation. The limb should be held in an easy and natural position and one which will ultimately be of use to the patient. In the case, for example, of a musculospiral paralysis, far better results will be obtained by using a small cock-up splint in the palm, and allowing the fingers to flex, than by maintaining these in an extended position.

INDICATIONS FOR OPERATION.

The indications for operation do not depend on the results of any one examination, but upon the close consideration of the progress of the case. It is therefore our custom to see every case at the earliest opportunity, and to make exhaustive notes of the condition found, although from the nature of the wounds it may be obvious that an operation cannot be contemplated for several months. The case is seen every month, and any changes are noted on charts. The question of operation is not considered until the wounds have been soundly healed for two months, when such a mass of information has been collected that a decision is no longer difficult. If the nerve shows signs of active recovery, operation will be deferred. Such signs are—a reduction in the area of anæsthesia, or a quickening in the galvanic response of the muscles, especially a shortening of their period of relaxation. If, however, there is little or no recovery, it is far better to explore and to discover the actual condition of the nerve than to waste further time in waiting. But before undertaking an exploration, the surgeon should have a very clear idea as to whether resection of the nerve will be required, or whether freeing it from scar tissue will suffice. The most difficult cases of all to deal with are those in which a portion only of the nerve is totally destroyed. In these the most careful record must be made of the voluntary movements present, and the operation must be performed under control of repeated electrical stimulation of the nerve, as only in this way is it possible to discover and preserve the uninjured fibres. We are strongly in favour of exploring all doubtful cases; in looking through our records we much regret that we did not always take this course. It is one thing to suggest exploration to a patient soon after an injury, and quite another to advise it after six months of abortive treatment.

CONDITIONS FOUND.

As regards the conditions found at operation, it is possible to lay down one general premiss—the injury to the nerve is always much more considerable than might have been expected from the clinical signs. The fact is that the nerves contain a great excess of fibres above those actually required, and a third of the cross-section must in general be destroyed before any permanent disability will result. The portion of the nerve which is injured is very obvious, its natural soft and striated structure being replaced by a dense knot of fibrous tissue. In some cases this will occupy the whole of the nerve; in others only a portion of its structure is destroyed, the remaining fibres passing down as a more or less uninjured band. In such cases we test the electrical conductivity of the nerve by bipolar stimulation with the faradic current above and below the point of injury. Owing to a partial block at the site of injury stimulation above will almost always require a more powerful current than stimulation below, and the strength of the current required gives some indication of the condition of the fibres concerned.

In other cases so much of the nerve will have been destroyed that no continuity exists, there being a gap of several inches between the last discoverable portions of the nerve, which, in such a case, will usually terminate in end-bulbs. Sometimes one end of the nerve will be found embedded in bone by the projectile which caused the injury. In one of our cases this last condition gave rise to a sciatic causalgia so severe that the nerve had to be divided in the open wound.

In other cases the nerve can be shelled out from dense fibrous tissue, in which it is apparently being strangled. In some of these the nerve, when freed, may present no abnormality in appearance or consistence, beyond a slight constriction, the injury apparently being entirely limited to the perineural structures. In general, however, there will be some degree of fibrosis in the nerve itself. The slighter degrees of injury are those most frequently associated with pain, which would seem to be due to a definite neuritis rather than to the actual trauma, for the nerve is often found to be swollen and indurated for some distance above the point of injury.

In testing these nerves electrically, we use two small metallic points, placed at a

distance of about four millimetres, and connected with a weak faradic source. We are in the habit of gauging the strength of the current by applying these electrodes to the neighbouring muscle, and we would call attention to the fact that a muscle whose nerve is already divided responds to such stimulation with the slow contraction typical of the reaction of degeneration. It is therefore an error to state without qualification that a paralyzed muscle cannot respond to faradic stimulation.

INDICATIONS FOR RESECTION.

If the continuity of a nerve is found to be completely destroyed, either absolutely or by a fibrous knot, it is of course obvious that recovery can only be obtained by resection of fibrous portions and direct suture of the uninjured trunks. If any fibres of the nerve remain which have escaped injury and can be dissected from the injured part, these should be most carefully preserved, provided that this can be done without prejudice to the suture of the remaining portion. We are convinced, however, that it is a mistake to spend too much time in saving a few fibres of doubtful utility. Clean resection of a whole nerve can be carried out with much greater precision than is possible when a portion of the nerve is left.

The most difficult cases in which to reach a decision are those which are associated with extreme pain in the nerve distribution. The pain can certainly be abolished by alcoholic injections, but where a part of the nerve is destroyed and resection is essential, alcoholic injections may seriously prejudice the ultimate result. In partial lesions associated with severe pain, where a considerable portion of the nerve is definitely fibrosed, we prefer complete resection of the nerve with end-to-end suture.

There is no detail in the surgery of nerve injuries which calls for more experience or where a careful judgement is more essential. Our experience so far favours complete resection with end-to-end suture in all cases where there is not some very obvious reason for taking another course.

OPERATIVE TECHNIQUE.

To a surgeon who proposes to operate upon the peripheral nerves, accurate knowledge of their anatomy is essential, and it is difficult to see how the intimate knowledge required can be obtained except by spending some time as a demonstrator in the dissecting room.

The difficulties of identifying the two ends of a divided nerve, in a limb where all the ordinary landmarks have been destroyed, can scarcely be exaggerated. One has to rely for their discovery on minute details, or else to make dissections which are mutilating in their extent. Unfortunately this is far from being universally recognized, and it is no uncommon thing for a man whose anatomical studies ended with his student days to attempt a complete dissection of a brachial plexus from a fibrous scar, a feat of which any anatomist might well be proud. It is surely most unfair to a patient that any surgeon should undertake such a critical operation as the suture of a nerve without equipping himself by every means in his power to meet the difficulties he may encounter.

Exposure.—An incision is made in the course of the affected nerve of such dimensions that the peripheral and distal portions of the nerve can be readily found in approximately normal tissue. This is far better than to attempt first to discover the nerve in the actual scar tissue, where it may quite well have ceased to exist. The ends exposed, these are carefully followed into the scar, and the whole nerve or its divided ends are then isolated.

In exposing the nerve, as little damage to surrounding structures should be done as is practicable; but it must always be remembered that the recovery of the nerve is the aim of the operation, and that very heavy sacrifices may be desirable if this object is obtained. The complete division of a large muscle such as the gluteus maximus, or the resection of several inches of the humerus, would in general be bad surgery; in the surgery of nerves such proceedings may be essential. It is impossible to reach the

sciatic nerve in the neighbourhood of the pelvis without dividing the gluteus maximus; and although it may be sometimes possible to turn down a portion of the muscle, or to divide it in the direction of its fibres, cases will occur where the only satisfactory course is to divide it transversely.

Testing Conduction.—The nerve satisfactorily exposed, it is necessary to decide, if it is not already divided, upon the advisability of a resection. To a large extent the decision will have already been made, and will depend upon the previous course of the case. In all cases, however, we test the conductivity of a continuous nerve to faradism, both above and below the point of injury. If conduction through the injured portion is not seriously impaired, and if the degree of fibrosis of that portion is not extreme, it is better to be content with having freed the nerve, dissected it free from all fibrous tissue, and formed for it a protective bed of fat or muscle. If conductivity is poor, and fibrosis is extreme, resection of the damaged part is in general to be preferred

Resection.—A question of great importance now arises—the extent of resection which is possible, or advisable, if end-to-end suture is to be performed. We can here lay down two propositions which cannot be disputed. First, that unless so much of the nerve is resected that healthy fibres are exposed, the operation will be nugatory. Second, that the results of end-to-end suture far surpass those of any other method at present known. We therefore decide first upon the length of nerve which will probably have to be removed before healthy fibres are reached; and then try to devise some means for bringing the nerve ends together. If the nerve be widely freed above and below, it is remarkable how much can be removed without producing undue tension after suture, provided the position of the limb is carefully arranged. Thus, we have resected nearly three inches of the ulnar nerve, and obtained a direct suture by flexing the wrist, extending the elbow, and adducting the arm close to the side. We prefer this method in most cases to the more drastic one of dislocation in front of the condyle. In the latter the branch to the flexor carpi ulnaris is very liable to injury. For the median, flexion of the wrist and elbow, and adduction of the arm, will allow of the resection of at least two inches. In the case of the sciatic, it is actually possible to resect five inches, if the nerve is widely freed, the knee flexed, and the hip hyperextended. In the arm, if these limits are exceeded, we have not the slightest compunction in resecting as much as may be necessary of the humerus.

We would lay very great stress upon the superiority of end-to-end suture over all other methods in dealing with a divided nerve. In very rare cases anastomosis to another nerve may be justifiable, but in the present state of nerve surgery it should only be done with the clear understanding that an experiment is being performed. Flap operations are occasionally successful. As to grafts, in spite of the prominence which is given to them in text-books, we know of few cases—the records of which will stand investigation—in which a successful result has been obtained. Doubtless a successful technique will one day be discovered; at present it does not exist. From cases which we have observed, we think it possible that the nerve fibres grow into the graft, but meet with a hopeless barrier at its lower end. If this is so, a secondary resection at the lower end of the graft might prove successful; we have not had, so far, the opportunity of carrying this out. It is a question which might well be the subject of a series of animal experiments. At present we strongly hold that direct suture should be carried out at any cost in every case, or that the operation should be abandoned in favour of tendon transplantation or some other method of restoring function.

Suture.—The actual suture of a divided nerve is a simple matter, but it demands an accurate technique. It is essential that the nerve should be handled as little as possible, and that the cut ends should not be handled at all. The nerve being held by its fibrous portion, a suture of ordinary fine catgut is passed transversely through its substance a short distance above the ultimate point of section. The same suture is similarly passed through the nerve below the point of injury. With a Gillette blade, or a very sharp scalpel, the nerve is now divided as near to the point of injury as healthy fibres can be

expected. The end is then examined, and if the nerve bundles do not appear sufficiently normal, a further slice is removed, the nerve being always held by the part to be cut off. The suture is now drawn tight, so as to bring the cut ends into direct apposition. If considerable tension is anticipated, a second suture is passed at right angles to the first. In order to obtain apposition, the limb must of course be brought to that position in which the nerve is as slack as possible. With the finest obtainable catgut and very fine curved needles, separate sutures are now inserted to bring together the sheath of the nerve. As regards the depth to which these sutures should pass, we regard it as of more importance that they should have a secure hold than that they should be limited to the nerve sheath itself, which is sometimes far too delicate for security. From four to ten of these sutures may be inserted, according to the dimensions of the nerve.

It is of importance that the true relative positions of the proximal and distal portions should be preserved without rotation. In most cases, however, where the nerve has been totally divided by the injury, this will be largely a matter of surmise ; but in a composite nerve like the sciatic, it can always be obtained with a considerable approach to accuracy.

The Protection of the Suture Line.—This is a matter about which there is much difference of opinion. We ourselves always make use of pedunculated flaps of fat, or of the protection of adjacent muscles. By dexterous suturing, with perhaps a small longitudinal incision into an adjacent muscle belly, it is usually quite easy to remove a suture line from the area of scar ; and this is the method which we prefer. If this is impossible, there is usually no difficulty in turning a small flap of subcutaneous fat to form a sheath for the nerve. It is worthy of note that in several cases where we have used fat flaps for this and other purposes, and where we have had the opportunity of inspecting them at a later date, they have been found after a year or more to be intact and to form a permanent living protection. We have also explored old nerve sutures protected with Cargile membrane, and found this lying in the tissues as a loose foreign body ; for that reason we feel diffident as to its suitability for the purpose.

The muscles and fascia are then replaced and repaired with catgut sutures as carefully as possible, and the wound is closed without drainage, except in the case of large buttock wounds, where a tube is left in the upper part of the incision, and passing through the gluteus maximus, for twenty-four hours.

Relaxation of Tension.—The limb is now fixed by bandages or splints in such a position as to insure relaxation of the nerve. We rely chiefly upon bandages, as being more comfortable ; but an anterior splint may be necessary to keep the elbow extended in the case of an ulnar nerve. In the leg, the most effective method is to tie the foot to a waist-band by a loop of bandage drawn as tight as may be necessary ; in this way slight movements of the hip and knee are allowed in opposite directions, which greatly relieve the strain of the position without interfering with the relaxation of the nerve. Usually at the end of a week, and in difficult cases after ten days, all restraints are removed, and the patient is allowed to move his limb as he may wish. We find that this is a perfectly safe plan, for the stiffness resulting from the fixation will prevent him from undertaking any but the most cautious movements, whilst the strength of the suture line will be quite sufficient to withstand any voluntary stress to which he is likely to subject it. By the end of another week or fortnight the nerve itself will have stretched sufficiently to allow of full movements of the limb. We regard prolonged fixation as quite unnecessary, and very inimical to the recovery of the limb.

RECOVERY.

An injury to a peripheral nerve may be sufficient to destroy the vitality of the axon cylinders beyond its site, or it may only be sufficient to inhibit temporarily their conducting power. In the one case the whole of the distal portion of the nerve will die, and recovery can only occur by the complete Wallerian cycle. In the other, a simple recovery of function is all that is required. These two methods of recovery are sharply differentiated, and proceed on entirely different lines ; but it is always possible that an

injury, though insufficient to destroy the vitality of a nerve, may be sufficient to permanently prohibit a return of function, owing to the extent of the local degenerative changes which occur in the nerve and surrounding structures. In such a case it may be necessary to resect the damaged portion, in spite of the fact that a partial lesion is thus converted into a complete one.

In civil practice, nerves are frequently sutured in clean wounds a few hours after injury, before degeneration has had time to occur in the peripheral portion of the nerve. In military practice this does not occur, and it may be taken that the peripheral portion of the nerve has passed through the complete process of Wallerian degeneration before suture is attempted. This is in itself a very striking difference, and is sufficient to account for many of the discrepancies in observations made on civil and military cases.

Sensory Fibres.—The process of recovery after complete degeneration will be the same whether the recovery occurs spontaneously or after resection and suture. The axon cylinders will grow downwards from above into the degenerated peripheral sheaths, and the extent of their recovery may be traced by a sign of which we have made use from the earliest stages of our work, but which was first described by Tinel. Gentle tapping over the course of the nerve at a point to which recovery has reached produces a tingling sensation in its normal distribution. We have noticed an interesting and peculiar example of this sign in cases where we have anastomosed the peripheral end of an injured musculospiral nerve into the median: tapping on the back of the forearm produces tingling in the centre of the palm. As the axon cylinders grow downwards, both epicritic and protopathic forms of sensation have in our cases generally returned simultaneously. It is more common in civil practice for the protopathic sense to return at an earlier date. Once recovery has begun, the anæsthetic area rapidly contracts and disappears, though in the case of an ulnar injury it is remarkable how slowly the little finger recovers. We are speaking of the crude tests with brush and pin to which we have already referred. Compass sensation, and those finer forms of tactile appreciation which are essential to the full utility of a limb, are slow in their return. Many of these avenues of sense depend upon complex cerebral connections for their perfection, and it is to that region rather than to the peripheral nervous mechanism that we must look for their recovery.

Motor Fibres.—On the motor side, the first evidence of recovery that we have observed is a shortening of the period of relaxation after galvanic stimulation. This is followed by a quickening of contraction to the same stimulus. In our own observations, voluntary power returns in general before any response to faradism can be obtained. On this point we are at variance with other observers; but it is a question in which the personal equation of the observer must always prove a large factor. It is obvious that an observer who depends more upon mental suggestion will obtain different results from one who relies rather upon the strength of his batteries. It is at any rate certain that faradic response and voluntary power return almost simultaneously. But though these are the views we hold, we would sound one note of warning. There is nothing in which one is so likely to be deceived as in the recovery of the voluntary power to perform a given movement. It is probable that for months the enthusiastic masseuse has been endeavouring to get the patient to perform the movements typical of recovery; and the ingenuity which he will display in carrying out her wishes is remarkable. To many of these false movements we have already referred; but in addition to these, there is a large group dependent upon slight contractures. Thus, in paralysis of the musculospiral, where the hand has been kept dorsiflexed in irreproachable position, the extensor muscles tend to become slightly shortened, and the flexion of the wrist will now produce a very fair imitation of a true extension of the fingers. Similarly, a shortening of paralyzed flexors may enable the patient to flex his fingers by extending the wrist. Unusual connections of the tendons are another source of error; we at present have a patient with musculospiral paralysis who can extend the terminal joint of his thumb by means of the abductor brevis pollicis, that muscle having, in his case, its unusual insertion into the dorsal expansion of the thumb.

FUNCTIONAL RESULTS OF NERVE SUTURE.

Recovery of function in a nerve is an extremely complex process, and is by no means summed up as the down-growth of axon cylinders. It is true that until this has taken place no recovery of function is possible; but this recovery involves a re-education of the whole neuromuscular mechanism, of which this forms only a link. The actual histological recovery of the nerve will depend upon such factors as the time which has elapsed since injury, and the youth of the patient; but the recovery of function will depend upon the patient's energy, upon his mental alertness, and upon the skill with which his personal efforts are directed along proper channels. The prognosis of nerve suture is therefore a matter of great complexity, and the term 'recovery' is so relative as almost to cease to have a meaning. It is easy to define the 'clinical' course of a case, to follow the return of 'pin and brush,' and to obtain from the patient a certificate of 'recovery,' if this is all he requires. I have myself seen several cases in which the ulnar nerve was completely divided without causing any remark on the part of either the patient or his medical adviser. It is still more remarkable that in one of these cases the patient considered that he had a perfectly normal hand until, a year later, his attention was called to his condition; the hand immediately became perfectly useless.

Individual Nerves.—The prognosis will depend upon the complexity of the nerve itself and of the functions which it is expected to perform.

Musculospiral.—Suture of the musculospiral nerve gives results only exceeded by those of its branch, the posterior interosseous. It contains few sensory fibres, and those of little importance; and its function is the simple one of extension of the elbow, hand, and fingers. Most of its motor fibres will therefore reach their proper destinations, and will not be lost in sensory nerve endings. In a simple case of suture of this nerve, recovery, complete in every sense, is usually rapid and certain.

Ulnar.—The ulnar nerve, on the other hand, is a mixed nerve with an important sensory supply, whilst the muscles which it controls carry out the fine and complex movements of the hand. The chances of motor and sensory fibres reaching motor and sensory endings are far smaller than in the case of the musculospiral, whilst the recovery of the fine movements of the hand involves an amount of re-education which can rarely be obtained. Recovery of the ulnar nerve is therefore a slow and uncertain process. But it must be remembered that the number of people who make any separate use of their fingers is extremely small, and that except to these people an ulnar nerve is a luxury rather than a necessity. To the majority the loss of the ulnar nerve is a matter of no importance. To the watch-maker, the artist, the musician, it is probably an injury beyond repair.

Median.—Somewhere mid-way between these two nerves lies the median. Like the ulnar, it is a mixed nerve, and its fibres may miss their proper goal; it is, however, enormously 'overwired,' for above the elbow one-third of its fibres may be divided without any discoverable loss of function; whilst on the motor side it controls chiefly the large and entire movements of the hand. The prognosis of its suture has, in our cases, been fairly good, though it will be long before the finer forms of sensation return.

Sciatic.—In the leg we have found the prognosis very much better than we at one time thought it likely to be. The down-growth of the sciatic fibres has been much more rapid than could have been reasonably expected when one considers the distance over which they have to pass. In complete sutures at the middle of the thigh we have seen motor recovery begin within four months, and reach a very fair degree of power within the year. Its sensory fibres appear to be much slower in regenerating; but we regard sutures of the sciatic, even after resections of great extent, with considerable confidence.

A remarkable feature is the very perfect function of the leg in complete lesions of the sciatic nerve when the inevitable drop-foot is relieved by some simple spring device. Our patients appear to walk with perfect freedom and little fatigue, their chief trouble being the risk of injury to an insensitive foot.

ALTERNATIVE METHODS.

However perfect the technique of nerve suture may become, there will always be a residuum of cases of nerve injury to which it is not applicable, or in which for some reason recovery is not to be expected. In such cases we must fall back upon other methods, and it will be well to glance at the alternatives which are at our disposal.

Lower Limb.—In paralysis involving the lower limb it is almost always possible to compensate by some orthopædic appliance for the movements which are lost, for those involved are crude, and stability is of much greater importance than refinement of action. A boot with side-irons and an uplifting toe-spring provides an almost perfect substitute for the extensors of the foot, and even in the case of a completely divided sciatic nerve this simple appliance will enable a man to walk with little fatigue. Even in cases where the nerve has been sutured, it is almost always worth while to provide the man with such an instrument, that he may obtain proper exercise and maintain the nutrition of the limb during the period of recovery. Where the paralysis is likely to be permanent, it is worth while considering some internal method of support, such as tendon transplantation, or the introduction of artificial ligaments. The former is only applicable in cases where at least some of the muscles have escaped, but in injuries to the external popliteal nerve it may give brilliant results. In such a case the tendons of the tibialis posticus and flexor longus hallucis may be transferred to replace the paralyzed extensor muscles. In complete paralysis of the sciatic, Lange has furnished us with a very simple and effective method of supporting the foot by means of artificial ligaments of silk saturated with perchloride of mercury. We prefer the following modification of Lange's original formula. The silk is prepared by boiling in perchloride of mercury (1–1000), transferring to an alcoholic solution of perchloride (1–1000), and finally preserving in parolein. The silk, which should be a thick floss, must be passed actually through the bones which it is desired to approximate. Special holes are drilled for this purpose, and four or more strands of silk are used. Silk, so prepared, does not tend to cause suppuration, and in a few months it becomes converted into an inextensible structure indistinguishable from tendon.

Upper Limb.—In the case of the arm the problem is far more difficult, and all that can be done is to support the joints whose movements are affected in such a way that the remaining muscles may act to the best advantage. In the case of a paralyzed deltoid, the supra- and infraspinatus may hypertrophy to such an extent that they can abduct the arm satisfactorily; but if this is not the case, it is better to erase the shoulder-joint and obtain a bony ankylosis in an abducted position. This is also the best method of dealing with an irremediable paralysis of the flexors or extensors of the elbow. This disability, however, rarely occurs, for as a rule some portion of the triceps will retain its power, and even if the biceps and brachialis anticus are both paralyzed in a lesion of the musculocutaneous nerve, the supinator longus furnishes a very efficient flexor of the joint. Of course, if a satisfactory transplantation of tendon can be performed, the retention of the mobility of the joint is a distinct advantage; but it is a great mistake to sacrifice the function of the limb for the sake of that of the joint; and as regards the usefulness of the arm to the patient, we certainly feel much greater confidence in the simpler, if less ambitious, method of ankylosis.

In a musculospiral paralysis, the patient's most serious disability is the weakness of his grasp, owing to the want of fixation of the wrist. This can largely be remedied by the application of a small cock-up splint which only occupies the palm and does not interfere with the mobility of the fingers. We have also devised a glove, in which tapes represent the dorsal tendons, whilst a powerful elastic accumulator, which lies on the forearm and is attached above the elbow, furnishes the necessary extending force.

In the region of the wrist the transference of tendons has given excellent results, and the extensors of the wrist, fingers, and thumb may be replaced respectively by the pronator radii teres, flexor carpi ulnaris, and flexor carpi radialis. It is only rarely, however, that such operations will be required.

CONCLUSIONS.

In these brief notes we have attempted to sketch our own experiences in one of the most complex and difficult fields of surgery, in the hope that they may be of some slight assistance to those who, like ourselves, are groping for the solution of the many problems it affords.

One lesson has been so driven home to us, that, before we conclude, we should like to impress it upon others. Success in nerve surgery is a matter of organization. The investigation of the cases is so complex, the operations involve such unusual details of experience and technique, and the after-treatment required is so tedious and varied, that only by means of an extensive organization can they all be satisfactorily carried out. The highest operative skill is of no use in the face of incompetent physico-therapy, whilst the most perfect physical treatment is powerless to remedy the mistakes of a clumsy surgeon.

We would plead earnestly for the concentration of all nerve cases in centres where they will have at their disposal the extensive material resources, the clinical experience, and the trained patience without which their recovery is a matter of chance; and we would plead for routine and for simplicity in such a centre. Without routine, the department will rapidly degenerate into chaos; without simplicity of method, the routine examination and treatment of any considerable number of cases become physically impossible.

Our own nerve cases are entered on the lists of a special department at the earliest possible moment after they enter the hospital. A careful examination is made and recorded as soon as the patient is so far recovered as to enable it to be carried out. This examination is repeated once a month, and meanwhile he is every day under the close observation of the department until he leaves the hospital. After that an attempt is made to keep in contact with the man himself or his medical adviser. Only in this way is it possible to keep the continuous records upon which alone the man's treatment can be scientifically founded. Only thus can we prevent the formation of contractures, which may mean permanent and unnecessary disability. Only by such close observation can we choose the psychological moment for operation.

Hanging on the wall of the department is a large chart on which is entered the monthly examination of every patient. In a journal is given an exact account of his monthly progress, sensory, motor, and electrical. He is given a card on which are entered the details of his treatment for the coming month, and on the card is daily recorded each treatment which he receives; whilst his regular attendance for treatment is encouraged by a system of privileges. Each examination is conducted in the simple but complete manner which we have already described; anything less would be of little value; anything more would be exhausting to the patient and overwhelming to the investigator.

In operating, the surgeon should follow a simple and precise routine. He should have as clear and accurate a knowledge as is possible of the anatomy of the region, and of the condition of the nerve which he may expect to find. He should have a clear idea of what he means to do, and he should do it in the simplest manner possible.

The physical treatment of the case, before and after operation, should be based on a definite routine, although it should be directed to the special requirements of the patient, and should introduce all variety that is possible.

In short, the patient should feel that he is surrounded by a powerful organization, skilfully directed to his cure; and it should be the aim of the surgeon to make that organization so perfect, that a man may be supported, through the tedium of many months, by the knowledge that his cure is its inevitable result.

APPENDIX A.

TABLES OF NERVES TREATED.

In the following tables the nerves which we have treated are grouped under five classes, as follows :—

1. Followed to complete recovery. In a military hospital only a few cases can come under this class.

2. Recovering normally, and likely in normal time to reach *Class* 1. As far as possible we have retained our cases until we had positive evidence that they belonged to this class.

3. Recovery doubtful or delayed. It is hoped that many of these cases will recover ; but we had to part with them before we could be certain that this would be the case.

4. Total failures, after observation for at least a year. We do not expect these cases to recover.

5. Cases which we have not been able to follow up. In the Percentage Results this class is excluded.

It is to be noted that cases with multiple nerve lesions will appear in more than one table.

	Class 1. Recovered	Class 2. Recovering	Class 3. Doubtful	Class 4. Failures	Class 5. Unknown	Total
1. Sutures.						
Ulnar	1	12	—	1	5	19
Median	—	7	2	—	2	11
Musculospiral	1	3	—	—	1	5
Posterior interosseous	1	—	1	—	1	3
Brachial plexus	—	1	2	—	—	3
Sciatic, internal popliteal	2	4	—	—	2	8
Sciatic, external popliteal	2	5	2	—	2	11
Musculocutaneous	—	—	—	1	—	1
Total sutures	7	32	7	2	13	61
2. Neurolysis						
Ulnar	3	2	1	—	—	6
Median	1	3	—	—	—	4
Brachial plexus	1	8	—	—	—	9
Sciatic, internal popliteal	1	1	—	—	—	2
Sciatic, external popliteal	1	2	—	—	—	3
Total neurolysis	7	16	1	—	—	24
3. Anastomosis.						
Ulnar	—	1	—	—	—	1
Median	1	—	—	—	—	1
Musculospiral	—	2	—	1		3
Total anastomosis	1	3	—	1	—	5
Total Operations	15	51	8	3	13	90
4. No Operation.						
Ulnar	6	1	—	—	5	12
Median	2	2	1	—	3	8
Musculospiral	8	2	1	—	2	13
Posterior interosseous	2	—	—	1	—	3
Brachial plexus	—	2	—	—	—	2
Sciatic, internal popliteal	2	3	—	—	4	9
Sciatic, external popliteal	4	3	—	—	4	11
Total No Operations	24	13	2	11	18	58
Total of All Nerves	39	64	10	4	31	148

PERCENTAGE RESULTS OF CASES WHERE RECORDS ARE AVAILABLE.

	RECOVERED	RECOVERING	DOUBTFUL	FAILURES	TOTAL
Sutures	14	68	14	4	100
Neurolysis	29	67	4	—	100
Anastomosis	20	60	—	20	100
All Operations ..	20	66	10	4	100
No Operations ..	60	33	5	2	100
All Nerves	33	55	9	3	100

APPENDIX B.

ABSTRACTS OF CASE HISTORIES.

The following abstracts are intended to furnish, in the briefest possible space, a complete record of the work upon which this paper is founded. By examining them it is possible for anyone to ascertain the exact value which may be attached to the statements we have made and the opinions we have expressed. We trust that they will at least be found to be in accordance with the material upon which we have worked, and which we here produce.

The cases were under the charge of Captain L. E. C. Norbury, R.A.M.C., Captain A. Wills, R.A.M.C., Captain R. H. Campbell, R.A.M.C., Captain C. H. L. Harper, R.A.M.C., Captain W. Martin, R.A.M.C., and ourselves. In each case where an operation was performed the operator is indicated by his initials. For all observations and records we must accept the sole responsibility.

The following abbreviations have been used :—

R = Right. L = Left. V P = Voluntary Power. R D = Reaction of Degeneration. F = Faradism. G = Galvanism. P U =Permanently Unfit. SUMMARY = Summary of progress after operation.

ULNAR NERVE (OPERATED CASES).

Case 1.—*Feb.*, 1917.—Wound middle of R forearm. *March.*—Wound healed. Pressure upon it causes tingling in little finger. V P present in adductor of thumb and abductor of index, which react to F, but are sluggish to G. Other hand muscles of ulnar group have no V P, and show complete R D. Anæsthesia to wool and pin over distal segments of little finger. *April.*—Hypothenar muscles show small degree of V P. Wasting in third and fourth spaces, and clawing of little finger recovering. *Aug.*—All forms of sensation, except compass, present. *Oct.*—V P in all the ulnar group, which react to F, sluggish to G. Scar still tender to pressure. Operation advised. *Nov.*—OPERATION (W. M.). Ulnar nerve exposed in middle of forearm, and freed from adhesions. A fibrous nodule, resulting from partial division, found on its inner aspect. This was dissected off, without cutting deeply into nerve, and flap of fascia wrapped round it. *Jan.*, 1918.—V P (weak) in all hand muscles. Compass defective in little finger. No other sensory loss.

SUMMARY.—(11 *months*) *Almost complete recovery.*

Case 2.—*Jan.*, 1916.—Wound inner side of R elbow, fracture of inner condyle. Complete paralysis of ulnar nerve. *May.*—OPERATION (H. S. S.). Resection of ½ in. dense fibrous scar in nerve. Direct suture. Branch to flexor carpi ulnaris not divided. *July.*—V P in flexor carpi ulnaris. R D and no V P in other ulnar muscles. *April*, 1917.—Sensation recovering. V P in adductor pollicis. *May.*—No loss to wool, pin felt radiating. *Sept.*—Power recovering in all small muscles, and all react to F. *June*, 1918.—Doctor reports continued recovery.

SUMMARY.—(8 *months*) *Sensation recovering.* (10) *Power in abductor pollicis.* (16) *Power in all small muscles, sensation almost normal.*

Case 3.—*Oct.*, 1916.—Wound middle of R forearm. Partial fracture ulna. Ulnar paralysis. *March*, 1917.—Wound healed. Pressure causes pain in ulnar area. Complete ulnar paralysis of hand. Flexor tendons adherent, contracture of wrist. *July.*—Contracture reduced by splint. Complete wrist-drop, and loss of all movements of muscles of forearm, except flexors of thumb and index. All these muscles respond well to F. Ulnar hand muscles still show complete R D. *Jan.*,

1918.—Very slight power in portion of hypothenars only. Slight protopathic sensation in outer ulnar area. Total loss in little finger and adjacent hand. *March.*—OPERATION (H. S. S.). Explored. Nerve found almost completely divided, though conducting F to all muscles weakly. Resection suture over 2-in. gap. *May.*—Complete sensation in ring finger, probably overlap. Normal loss in remainder of ulnar area.

Case 4.—*July*, 1916.—Small wound front of R wrist. Partial lesion of ulnar. *Oct.*—Weakness of all interossei. Fair power in adductors of thumb, slight numbness in ulnar area. OPERATION (H. S. S.). Anterior part of nerve found divided. Posterior part conducted F. Fibrous part excised, and nerve protected from scar by fat sleeve.

Case 5.—*July*, 1916.—Large, deep wound involving whole of inner side of L forearm. Complete lesion of ulnar. *Oct.*—Wound closed by graft. Complete ulnar anæsthesia, and paralysis with R D ulnar hand muscles. Claw hand. *March*, 1917.—OPERATION (H. S. S.). Ulnar nerve exposed in forearm, 6 in. densely fibrosed ; did not conduct to F. On section no fibres visible. Distal end carried across forearm, between deep and superficial flexor tendons, and implanted into inner side of median. No interference to conduction of F by median resulted. *April*, 1917.—V P all median muscles. Sensory loss. *Nov.*—No evidence of recovery. *June*, 1918.—Doctor reports power and sensation returning.

SUMMARY.—(14 *months*) *Power and sensation returning.*

Case 6.—*Sept.*, 1916.—Small perforating wound L arm, just below axilla. *Oct.*—Numbness in ulnar border of L hand, with some pain in this region. V P lost in ulnar muscles. Complete loss to pin and wool in ulnar area. *Nov.* 4.—Pain shooting in character. Ulnar sensitive to pressure at elbow. Thrill and expansile pulsation at wound over brachial. OPERATION (H. S. S.). Aneurysmal varix, with well-marked communication between vein and artery. Pressure on ulnar nerve, which was flattened, thick, and fibrous. Vein adherent to median and ulnar nerves. Fibrous tissue and recent blood-clot around vessels. *Nov.* 7.—Complete recovery, all forms of sensation and V P in 3 days. *Dec.*—Discharged fit for duty.

SUMMARY.—(3 *days*) *Complete recovery.*

Case 7.—*Feb.*, 1917.—Wound inner side of L arm, just above elbow ; fracture of humerus. Ulnar paralysis. *April.*—Wound healed. Ulnar anæsthesia. Pressure on ulnar at elbow produces radiating pain in fingers. No V P and complete R D in ulnar muscles. *May.*—OPERATION (R. H. C.). Almost complete anatomical division at bend of elbow. Resection 1½ in. Nerve dislocated and sutured directly. *Aug.*—Doubtful V P in flexor carpi ulnaris. No return of sensation. Transferred to Warrington.

Case 8.—*May*, 1917.—Perforating wound inner side middle of R forearm. Ulnar paralysis. *June.*—Paralysis, and R D in ulnar hand muscles. Fingers contracted from fibrosis in wound. *Aug.*—OPERATION (W.M.). Complete division. Direct suture, from 1-in. gap. *Sept.*—Transferred to Dartford.

Case 9.—*Oct.*, 1916.—Large wound flexor surface R forearm. Fractured ulna. Ulnar paralysis. *Feb.*, 1917.—OPERATION (R. H. C.). 3½ in. nerve found completely destroyed. Bridged by flap method, junction buried in muscle fibres. *May.*—Pressure on nerve 2 in. below line of suture causes tingling in ulnar distribution. Discharged P U. *Nov.*—Reports considerable recovery of sensation. No treatment. *June*, 1918.—Letter from patient. States has had no treatment, thinks there is a little further improvement.

SUMMARY.—(6 *months*) *Considerable sensory recovery.*

Case 10.—*July*, 1916.—Large wound front of R forearm. Fractured ulna and destruction of muscles on inner aspect. Complete ulnar paralysis. *March*, 1917.—Paralysis complete. Wound sound. OPERATION (H. S. S.). Nerve found completely divided, and 3½ in. missing. Proximal end cut across under biceps, and implanted into radial. Distal end carried beneath superficial flexors, and implanted into radial, which was cut across at both points. (*Figs.* 281, 282.) *April.*—Sensory loss in ulnar and a large radial area. R D all ulnar muscles. *Jan.*, 1918.—No sign whatever of recovery. *June.*—Doctor reports no evidence of recovery.

SUMMARY.—(12 *months*) *No evidence of recovery.*

Case 11.—*Aug.*, 1916.—Wound across front of R wrist, involving ulnar nerve. *Oct.*—Wound healed. Complete ulnar paralysis. *March*, 1917.—OPERATION (H. S. S.). Ulnar found completely divided, two end bulbs, with 1½ in. gap. Gap closed by transplant from radial, doubled. *July.*—Sensation recovering. No return of V P. *Aug.*—Transferred to Warrington.

SUMMARY.—(4 *months*) *Commencing sensory recovery.*

Case 12.—*Sept.*, 1916.—Small wound inner side of L upper arm. Paralysis of ulnar and internal cutaneous. *Nov.*—OPERATION (H. S. S.). Ulnar dissected out of dense fibrous tissue. Fibrous swelling. Internal cutaneous completely divided. Fibrous portion 1¼ in. excised from each. Direct suture. Fat sleeve. *July*, 1917.—Slight recovery of sensation in area of both nerves. V P present in flexor carpi ulnaris. Other muscles R D, and no V P. *Oct.*—Function as before. Ulnar sensitive to pressure just below elbow. Above, nerve thickened and insensitive. *Jan.*, 1918.—Doubtful V P in flexor carpi ulnaris. No other change. Nerve still sensitive 3 in. below elbow. *April.*—Massage sister reports sensation recovered to web of fingers, general movements of

hand much improved. F response in flexor carpi ulnaris, flexor profundis digitorum, abductor minimi digiti, flexor minimi digiti ; none in interossei. *June.*—Doctor states ulnar recovering.

SUMMARY.—(12 *months*) *Nerve sensitive to pressure in forearm.* (18) *Advanced recovery sensory and motor.*

Case 13.—*July*, 1916.—Wound L forearm. Fractured ulna. Complete paralysis ulnar nerve. *Nov.*—Complete paralysis, sensory and motor. R D hand muscles. OPERATION. Nerve explored. Complete division found. Fibrous part excised. Direct suture. *Sept.*, 1917.—No recovery of power or sensation. OPERATION (L. E. C. N.). Nerve explored. Fusiform thickening distal end.

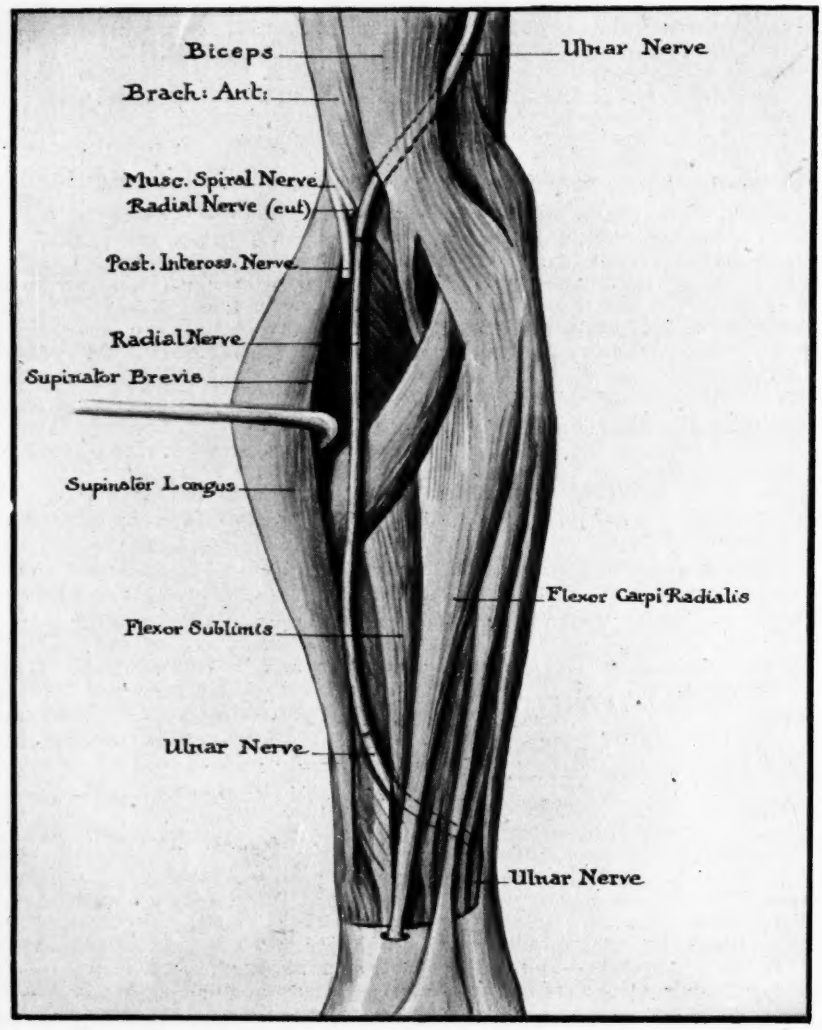


FIG. 281.—Use of the radial as a graft for the ulnar, without displacement of the former. (*Anatomy*) *Case* 10.

No end bulb on proximal end, fibres of which spread out in a fan, and attached to thickening on lower end. Resection of 1¼ in. Direct suture of apparently healthy ends. No conduction observed to direct F, and no evidence of recovery. *Jan.*, 1918.—Tingling on pressure 1 in. above pisiform. *April.*—Slight recovery small muscles of hand.

SUMMARY.—*After second operation* (10 *months*) *Commencing recovery in small muscles of hand.*

Case 14.—*March*, 1917.—Wound L forearm, inner side near elbow. Ulnar paralysis. Also penetrating wound of R parietal region of skull, with paralysis of L arm, which was recovering five weeks later. *May.*—Complete ulnar anæsthesia, and paralysis of ulnar hand muscles, with R D. *Sept.*—OPERATION (R. H. C.). Explored. Complete division found in upper forearm, with two end

bulbs. These were removed, and gap of 2 in. bridged by dislocating nerve to front of forearm, after division of humeral head of flexor carpi ulnaris. Buried in muscle. *Nov.*—Slight V P in flexor carpi ulnaris.

Case 15.—*July*, 1916.—Wound R forearm. Fractured ulna. Paralysis. *Sept.*—Ulnar anæsthesia. R D ulnar hand muscles. *Nov.*—OPERATION (H. S. S.). No conduction. Resection suture. *Nov.*, 1917.—Sensation recovering.

SUMMARY.—(12 *months*) *Some sensory recovery.*

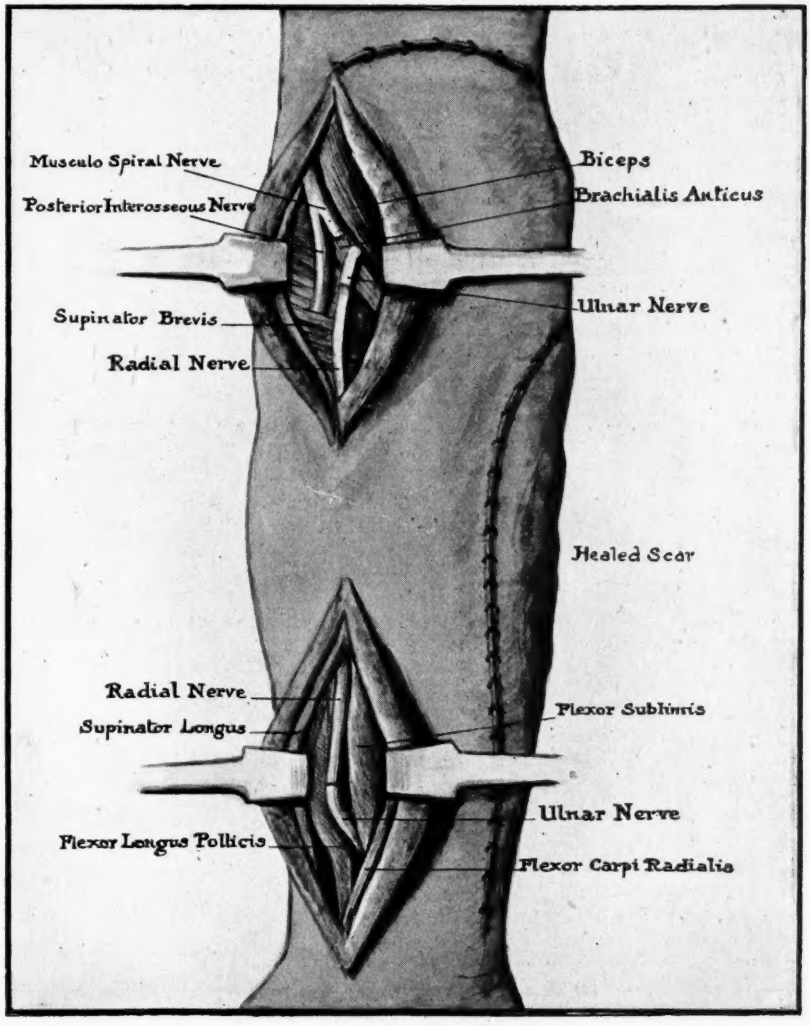


FIG. 282.—Use of the radial as a graft for the ulnar, without displacement of the former. (*Operation*) *Case* 10.

Case 16.—*July*, 1916.—Wound inner side R forearm. Compound fractured ulna. Paralysis ulnar nerve. *Oct.*—Wound healed at middle of ulnar border of forearm. Complete ulnar anæsthesia, with loss of power. R D in hand muscles. *Nov.*—OPERATION (H. S. S.). Nerve showed small hard bulb near scar. Stimulation with F above this gave no response, but below the bulb stimulation made hypothenars contract. Bulb resected ½ in. Direct suture. A few fibres could be seen to traverse bulb. *July*, 1917.—Recovery of protopathic all except little finger. No recovery of V P. *Oct.*—Sensation recovering. Chilblain over tip of little finger covers only area of protopathic loss. *Jan.*, 1918.—Sensation complete, except little finger. No recovery of motor power.

SUMMARY.—(8 *months*) *Extensive sensory recovery.* (12) *Sensory recovery almost complete, no motor recovery.*

Case 17.—*July*, 1917.—Small perforating wound R arm, above internal condyle. Paralysis ulnar nerve. *Aug.*—Wound healed. Complete ulnar paralysis, motor and sensory, with R D. *Sept.*—OPERATION (H. S. S.). Dense fibrosis in nerve closely limited to point of injury. Resection of ½ in. exposed healthy fibres. Direct suture. Nerve gave no reaction to F. *Jan.*, 1918.—Touch partially felt at base of ulnar area. Pressure on nerve does not produce tingling. A hard tender nodule felt at point of anastomosis. *April.*—Good V P in flexor carpi ulnaris. Sensation recovering.

SUMMARY.—(6 *months*) *Sensory recovery commencing. Power in flexor carpi ulnaris.*

Case 18.—*Nov.*, 1916.—Small perforating wounds inner side R upper arm. Complete ulnar paralysis. *Jan.*, 1917.—Ulnar and internal cutaneous anæsthesia. Flexor carpi ulnaris shows weak V P, and reacts to F. Ulnar hand muscles no V P, complete R D. *March.*—OPERATION (H. S. S.). Ulnar found divided, embedded in dense adhesions, no conductivity to F. Excision of fibrous ends left 1½-in. gap, closed by direct suture. Internal cutaneous not seen. *July.*—Ulnar sensitive at elbow, slight sensory recovery. Internal cutaneous largely recovered. *Oct.*—Ulnar sensitive at wrist. *Jan.*, 1918.—Ulnar sensation commencing to return. Pin and touch complete in internal cutaneous, but localization defective. Power of forearm muscles good. No recovery in hand muscles.

SUMMARY.—(4 *months*) *Nerve sensitive at elbow.* (8) *Nerve sensitive at wrist.* (10) *Sensory recovery commencing.*

ULNAR NERVE (CASES NOT OPERATED.)

Case 19.—*June*, 1917.—Wound L forearm. Fractured ulna. Ulnar paralysis. *July.*—Partial ulnar anæsthesia, partial paralysis hand muscles; all of which act normally. *Sept.*—Sensation recovered, including compass. Good power in ulnar muscles. *Oct.*—Complete recovery.

SUMMARY.—*Complete recovery in* 4 *months from injury.*

Case 20.—*May*, 1917.—Wound L wrist. Complete ulnar paralysis of hand. Compound fracture femur. Discharged Australian hospital.

SUMMARY.—*Transferred without operation.*

Case 21.—*Oct.* 1916.—Septic wound back of L forearm. Paralysis ulnar nerve. *Dec.*—Complete ulnar paralysis in hand, with R D and anæsthesia. *Feb.* 1917.—Anæsthesia recovered. Slight V P in hypothenars only. *April.*—Pin felt, except over last two joints of little and ring fingers. Slight power all hand muscles. *Jan.*, 1918.—Complete recovery.

SUMMARY.—*Complete recovery* 4 *months from injury.*

Case 22.—*Feb.*, 1917.—Accidental fracture L radius and ulna, clean wound on flexor surface, middle of forearm. *April.*—R D and no V P ulnar hand muscles. Partial ulnar anæsthesia. *June.*—V P present all hand muscles. Sensation returning. *Sept.*—Nerve completely recovered.

SUMMARY.—*Complete recovery* 7 *months from injury.*

Case 23.—*June*, 1916.—Wound L forearm. Fractured radius. Ulnar paralysis. *Nov.*—Complete motor and sensory paralysis, with R D. Transferred to Canadian hospital.

SUMMARY.—*Transferred without operation.*

Case 24.—*June*, 1916.—Wound inner side L elbow. Ulnar paresis and anæsthesia. *Sept.*—Sensation almost entirely recovered. Weak V P in all muscles. Discharged.

SUMMARY.—*Complete recovery* 3 *months from injury.*

Case 25.—*Sept.*, 1916.—Large wound inner side of R arm above elbow. Fractured humerus. Ulnar paresis. *April*, 1917.—Ulnar, internal cutaneous, and partial median anæsthesia. V P, and normal electrical reactions in all muscles. *June.*—Power improving. Sensation still impaired in ulnar area. *Aug.*—Discharged P U.

SUMMARY.—*Incomplete recovery* 12 *months from injury.*

Case 26.—*Nov.*, 1916.—Wound R forearm, inner side of wrist. Amputation R foot. *Feb.*, 1917.—Complete ulnar paralysis in hand. *July.*—No recovery. Discharged to Brighton.

SUMMARY.—*Transferred without operation.*

Case 27.—*Sept.*, 1916.—Large wound inner side of L arm above elbow. Ulnar seen to be divided, 2 in. missing. *Nov.*—Complete ulnar and internal cutaneous paralysis, with R D. *Feb.*, 1917.—Transferred to Taplow.

SUMMARY.—*Transferred without operation.*

Case 28.—*Aug.*, 1916.—Wound L arm. Fractured humerus, with large septic wound. *March*, 1917.—Complete ulnar paralysis. Ankylosis of elbow. Bone united with large amount of callus. *April.*—Partial ulnar anæsthesia. V P ulnar hand muscles. Ulnar nerve conducts to F, to hand muscles. 2nd dorsal interosseous reacts to F. Others nil to F or G. *Aug.*—Recovery of protopathic, but not epicritic, over whole ulnar area. V P slight in all ulnar hand muscles. *Sept.*—Epicritic completely recovered. Good V P. Complete bony ankylosis of elbow, in useful position. *Oct.*—Complete recovery. Discharged P U, on account of elbow.

SUMMARY.—*Complete recovery* 15 *months from injury.*

MEDIAN NERVE (OPERATION CASES).

Case 29.—*April*, 1917.—Deep, excavated wound over front of L wrist, radial side. Median nerve destroyed. *June.*—Wound healed. Above it bulb is felt, very tender and giving radiating pain in median area. Median anæsthesia in hand, with paralysis of small median muscles. *July.*—OPERATION (H. S. S.). Complete division of nerve, with large end bulb, and 1½-in. gap. Flap turned down, with partial amputation of bulb, and sutured to distal end. (*Figs.* 283, 284.) *Oct.*—Pressure over lowest point of flap causes radiating pain in fingers. *Jan.*, 1918.—No recovery. Bulb appears to be forming at end of graft which gives radiating pain on pressure.

SUMMARY.—(6 *months*) *Recovery to distal end of graft, with formation of bulb. Second operation to be performed.*

Case 30.—*May*, 1917.—Wound L arm just above elbow. Median paralysis. *June.*—Anæsthesia in most of median area. Back of index hypersensitive. Paralysis, and R D all median muscles. *Sept.*—Some V P all median muscles except opponens. Sensation unchanged. *Oct.*—Some recovery of sensation. V P condition unaltered. *Nov.* 16.—OPERATION (H. S. S.). Median freed from adhesions in antecubital fossa. Dense adhesions, small fibrous nodules in nerve, which could not be excised. Longitudinal incisions made in nerve. Pedunculated fat flap. Nerve conducted F forearm only. *Nov.* 22.—Sensation unchanged. Hypersensitive back of index. *Dec.*—Discharged to Australian hospital.

Case 31.—*Dec.*, 1915.—Wound middle of L arm. Fractured humerus. Median paralysis. *Aug.*, 1916.—Slight V P in median muscles, which react to F. *Nov.*—Wound healed. No further recovery. Median anæsthesia. *Dec.*—OPERATION (H. S. S.). Indurated portion of nerve resected. Direct suture. *Feb.*, 1917.—No recovery. Transferred to Cheltenham. *Nov.*—Doctor reports apparently no recovery.

SUMMARY.—*No recovery in* 11 *months.*

Case 32.—*Aug.*, 1917.—Wound below middle of L forearm. Wound excised at C.C.S. same date, and primary suture of median performed. *Oct.*—Sub-total median anæsthesia. Paralysis, and R D in flexor longus pollicis and median muscles of thumb. OPERATION (H. S. S.). Nerve found in continuity, but fibrosed at suture line, and very friable. End-to-end suture, after resection of 1¼ in. Sections showed that no nerve fibres traversed the old suture line. *April*, 1918.—Pin produces radiating tingling at base of index and middle fingers, and over terminal portion of thumb.

SUMMARY.—(6 *months*) *Protopathic sensation returning.*

Case 33.—*June*, 1915.—Bullet perforated R wrist. Median anæsthesia in hand. *Aug.*—No improvement. Operation. ½ in. fibrous nodule resected. Direct suture with silk and Cargile membrane. Intense bursting pain in fingers, severe pain along course of nerve in arm and forearm. Nerve tender to pressure. *Nov.*—Median nerve exposed in middle third upper arm, 15 min. 90 per cent alcohol injected. Temporary relief, but pain in few weeks severe as ever. *March*, 1916.—OPERATION (H. S. S.). Nerve explored at wrist. Fusiform junction found surrounded by dense sleeve of fibrous tissue, which could, however, be dissected off. Silk sutures and Cargile membrane unaltered. They were removed. They appeared to have acted as foreign bodies, and lay free from connection with the fibrous tissue which surrounded them. As much fibrous tissue as possible removed, but nerve not resected. It was hoped that it was regenerating. Buried under muscle. No relief in symptoms resulted. *May.*—OPERATION (H. S. S.). Exposed. Freed from fibrous tissue. Nerve three times normal diameter for 6 in. above injury, and densely fibrous. Split longitudinally. Saline injected into proximal end. Improvement followed, but only lasted few days. *Aug.*—OPERATION. Exposed. 3 in. thickened and fibrous. Excised. Gap of 2½ in. filled by radial graft, 3½ in. Result, immediate cessation of all pain. *Jan.*, 1917.—Sensation commencing to recover. Discharged to duty at own request.

SUMMARY.—(5 *months after last operation*) *Sensation recovering.*

Case 34.—*July*, 1916.—Small wound front of R wrist. Median paralysis. *Oct.*—No V P. Complete R D short median muscles. Unusually small area median anæsthesia, limited to fingers 1 and 2. *March*, 1917.—OPERATION (H. S. S.). Complete division found. Two bulbs of 1½ in. gap. Suture by bulb-flap operation. (*Figs.* 283, 284.) *April.*—Sensory loss as before. *May.*—Extensive recovery, no loss to wool, pin blunted. *June.*—Transferred to Ireland. *Nov.*—Reports no treatment, and no recovery. *June*, 1918.—Reports fingers still numb.

SUMMARY.—(2 *months*) *Extensive sensory recovery apparently not maintained.*

Case 35.—*July*, 1916.—Small wound centre of R forearm. Median paralysis. *Jan.*, 1917.—Protopathic loss only, R index and middle fingers. Paralysis, but no R D median forearm muscles. R D in opponens. OPERATION (R. H. C.). Median exposed, did not conduct. Excision of fibrous portion with direct suture. *Feb.*—Slight increase in area of sensory loss. *Nov.*—Reports power in forearm and sensation returning.

SUMMARY.—(10 *months.*) *Commencing motor and sensory recovery.*

Case 36.—*July*, 1917.—Wound R axilla. Ligature axillary artery and vein. *Sept.*—Severe causalgia with tenderness in palm of hand three days after wound. *Oct.*—Pain better. Healed. *Nov.*—Hyperæsthesia median area, to all forms of stimulation, with anæsthesia median fingers, front and back. Skin red and mottled. Paresis median forearm muscles, thumb wasted, doubtful V P, R D. *Nov.* 16.—OPERATION (H. S. S.). Much scar tissue in axilla, involving wide excision. Median and ulnar explored to their origins from cords. Median harder than normal, some neuritis; no lesion of sheath was seen, and it was readily shelled out from scar tissue. Conducted F to all muscles. Ulnar normal. *Dec.*—Hyperæsthesia in median area. Power improving. Pain

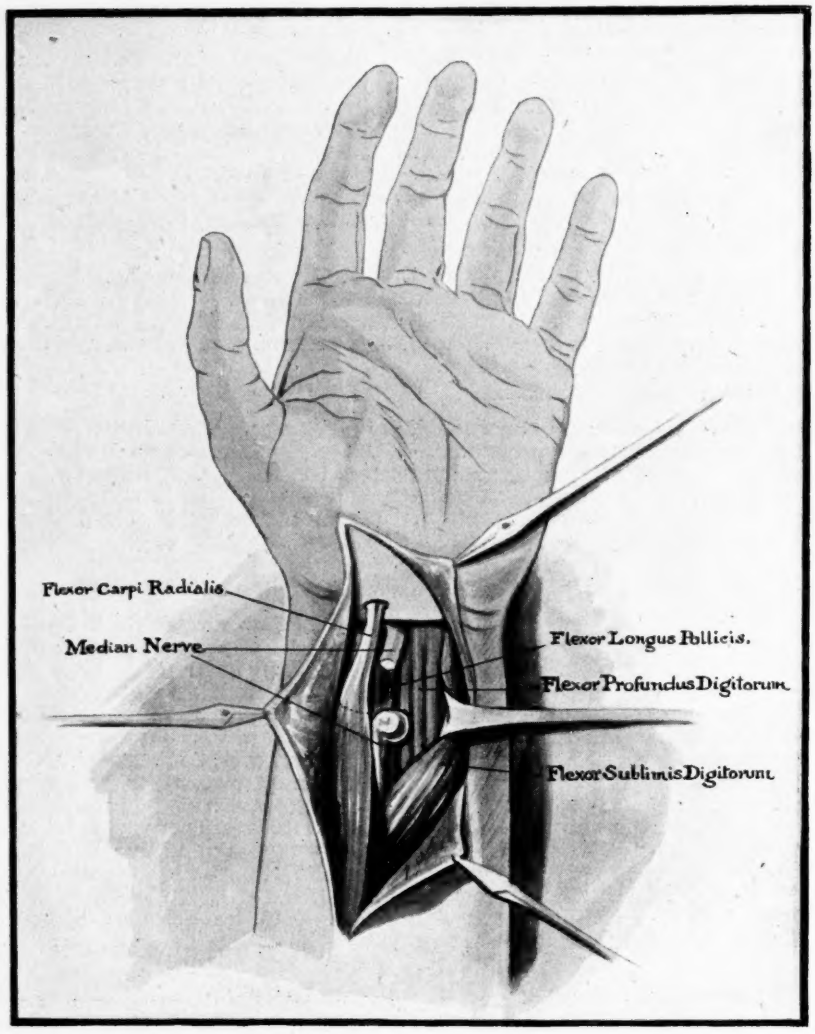


FIG. 283.—Bulb-flap operation, applied to the median. (*Step* 1) *Cases* 29, 34.

relieved by weak sinusoidal baths. *Feb.*, 1918.—Opponens and abductor have V P, but are wasted. *April.*—Pain has disappeared. Condition of arm improving, and muscles recovering power. *July.*—Almost completely recovered.

SUMMARY.—(1 *month*) *Reduction of pain, improvement in power.* (8) *Recovery almost complete.*

MEDIAN NERVE (CASES NOT OPERATED).

Case 37.—*April*, 1917.—Large wound back of L forearm. Fractured radius. Wrist drop. *June.*—Wound not quite healed. Union of radius incomplete. Muscles of forearm very weak, but wrist-drop disappeared. Anæsthesia to wool in median area. V P and F response in all

median muscles, except flexor longus pollicis. *July.*—Median area hyperæsthetic to pin. Power in median muscles poor. *Aug.*—Sensation recovering. V P in flexor longus pollicis. Transferred to Warrington.

SUMMARY.—*Recovering satisfactorily 4 months after injury.*

Case 38.—*April*, 1917.—Several small wounds L upper arm, one small fragment lying on median nerve removed. *May.*—Hyperæsthesia in median and internal cutaneous areas. No V P in opponens or flexor sublimis. Other muscles fair. *Sept.*—Hyperæsthesia same area, but less

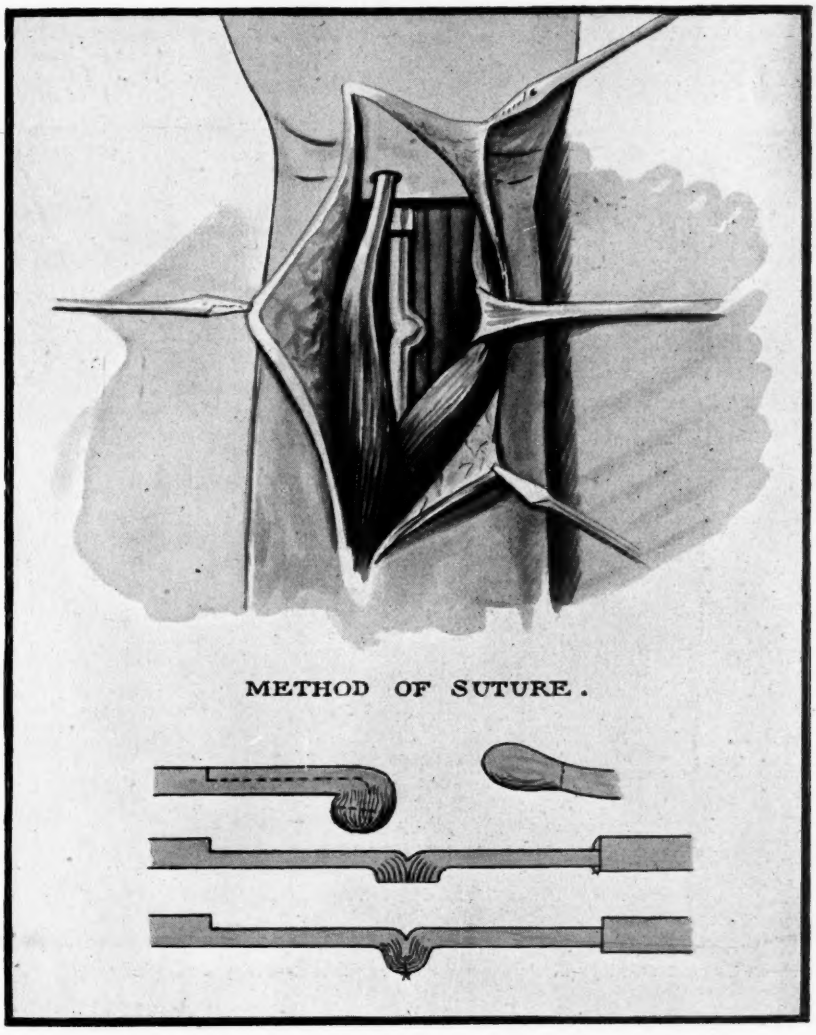


FIG. 284.—Bulb-flap operation, applied to the median. (*Step* 2) *Cases* 29, 34.

marked. Grip good, except with index. R D and no V P in opponens. Discharged Canadian hospital.

SUMMARY.—*Transferred without operation.*

Case 39.—*Jan.*, 1917.—Bullet perforated inner side L arm above elbow. Brachial artery tied for hæmorrhage. Median paralysis. *April.*—Numbness in middle and index fingers. Weak V P in median muscles, which react sluggishly to G, and not to F. *July.*—Median area feels numb, but is hyperæsthetic to pin. Power improving. Transferred.

SUMMARY.—*Recovering satisfactorily 6 months after injury.*

Case 40.—*Aug.*, 1916.—Wound L arm above elbow. Complete median loss of power and sensation, with R D. *March*, 1917.—Operation refused. No recovery. Discharged.

SUMMARY.—*Operation refused.*

Case 41.—*Oct.*, 1916.—Small multiple wounds R upper arm. *March*, 1917.—All wounds healed. *X* ray shows many fragments of metal around humerus. Internal cutaneous anæsthesia. Blunting to pin middle finger back and front. Pressure on median site of scar causes burning pain in middle finger. Wasting not marked, median fingers glossy. No V P flexor sublimus, longus pollicis, opponens, and abductor. R D of all these. Partial R D flexor carpi radialis and palmaris longus. Pronator radii teres no R D. *May.*—Middle finger hypersensitive to pin at front, blunt on dorsum. V P present all median muscles. *Sept.*—Middle finger still hypersensitive. Cannot completely flex index. Median muscles still weak; react to F, sluggish to G.

SUMMARY.—*Recovery poor* 12 *months after injury.*

Case 42.—*July*, 1916.—Large wound inner side R elbow. Median paralysis. *Aug.*—Partial median paralysis, some V P in flexor carpi radialis and opponens only. R D all median muscles. No loss to pin in median area, but brush imperfectly felt. *Sept.*—All median

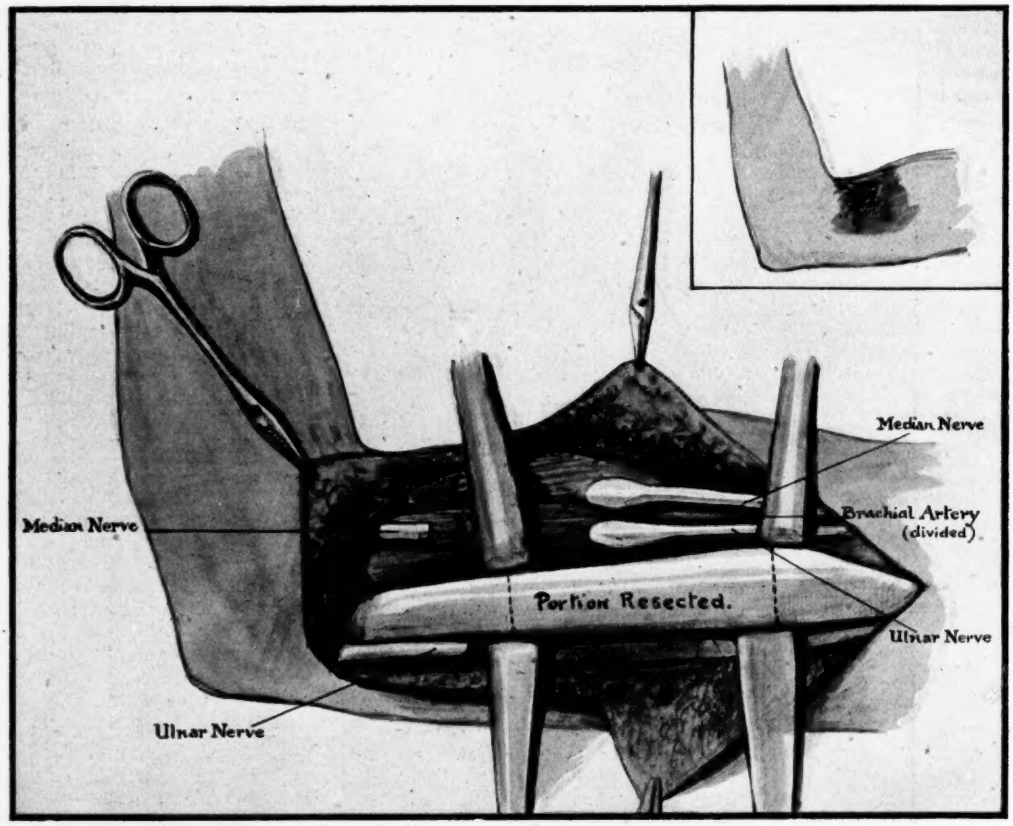


FIG. 285.—Median and ulnar injury. Resection of the humerus to obtain approximation. (*Step* 1) *Case* 48.

muscles, except flexor longus pollicis, recovering V P. *Nov.*—Complete recovery, sensory and motor. *June*, 1918.—Reports recovery.

SUMMARY.—*Complete recovery* 4 *months after injury.*

ULNAR AND MEDIAN NERVES (OPERATION CASES).

Case 43.—*July*, 1916.—Large through shell wound of L upper arm. Complete ulnar and partial median loss. *Aug.*—Severe causalgic pain in median area of L hand. *Oct.*—Alcoholic injection into median. Relief of pain, and total loss of median followed. *March*, 1917.—Still complete paralysis of median and ulnar nerves. OPERATION (L. E. C. N.). Nerves exposed in upper arm. Both looked degenerate, were fibrotic, but not completely divided. The median, much thinned at site of injection, gave way during stretching with a view to resection. It was impossible to bridge the gap, so the upper and lower ends were implanted laterally into the ulnar. *Nov.*—No evidence of recovery. *Jan.*, 1918.—Patient can flex wrist and fingers slightly, and appears to have some V P in all flexors of forearm. Some irregular sensory recovery in median

area. *April.*—Complete median sensory recovery. Good V P in all muscles of forearm except flexors of index and thumb. *May.*—V P flexors of index and thumb. All muscles of forearm respond briskly to G. Ulnar flexors respond to F.

SUMMARY.—(10 *months*) *Considerable recovery.* (12) *Complete median, extensive ulnar, recovery, sensory and motor.*

Case 44.—*May*, 1917.—Bullet pierced R upper arm inner side, cutting brachial artery. Complete median and partial ulnar paralysis, motor, and sensory. Total R D in median, incomplete in ulnar. *July.*—Recovered all forms of ulnar sensation, complete median anæsthesia. Feeble flexion in ulnar forearm muscles alone. All muscles give R D. *Oct.*—Feeble V P in ulnar and median forearm muscles. Area of anæsthesia diminished. *Jan.*, 1918.—No further improvement. Arm therefore explored. OPERATION (L. E. C. N.). Ulnar shelled out of dense fibrous tissue; conducted F to forearm. Median densely fibrosed, and did not conduct. 1½ in.

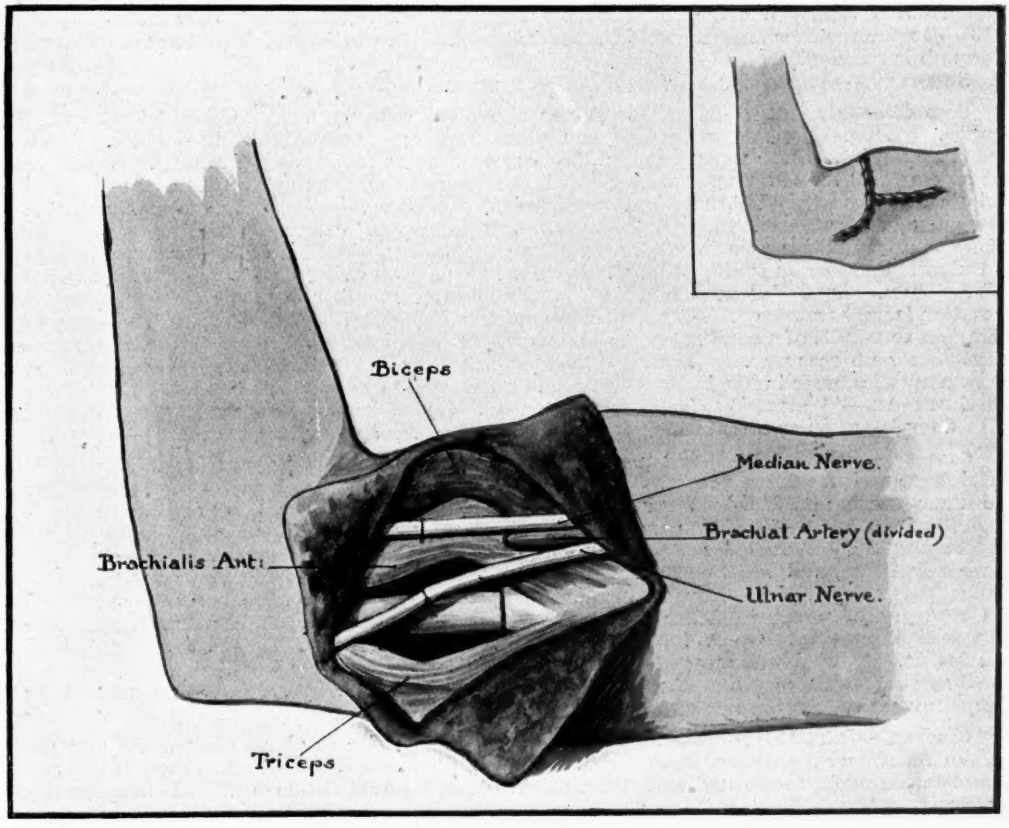


FIG. 286.—Median and ulnar injury. Resection of the humerus to obtain approximation. (*Step* 2) *Case* 48.

resected, end-to-end suture. *March.*—Good power in ulnar muscles of forearm. R D in all small muscles of hand. Total median paralysis. *April.*—Ulnar hand muscles respond to G stimulation of ulnar at wrist. *June.*—Anæsthetic area greatly diminished. Fair V P in ulnar muscles and in flexor profundus digitorum. *July*—Anæsthesia limited to terminal joints of index.

SUMMARY.—(4 *months*) *Ulnar recovery in forearm.* (6) *Advanced sensory recovery, complete in ulnar.*

Case 45.—*July*, 1917.—Bullet pierced L upper arm at middle of inner side. Complete sensory and motor paralysis of ulnar, median, internal cutaneous; except that pronator radii teres has entirely escaped. *Nov.*—OPERATION (R. H. C.). On exploration, ulnar found completely divided, and was sutured. Median was involved in scar, and thickened and indurated for 1 in. Conducted F to forearm muscles, but not to flexor longus pollicis, or to hand. It was freed only. *June*, 1918.—Sensation and V P recovering in both median and ulnar. (Report from Capt. Broad, Alder Hey.)

SUMMARY.—(8 *months*) *Recovery, sensory and motor, in both nerves.*

Case 46.—*Aug.*, 1916.—Large wound R arm, much destruction of tissue, Median sutured and brachial artery tied at C.C.S. *Sept.*—Median and ulnar anæsthesia, R D in muscles, but slight V P in flexors of wrist and fingers, none in hand muscles. *March*, 1917.—Anæsthesia as before, slight V P in flexor carpi ulnaris and profundus; no reaction to F or G in other muscles. OPERATION (H. S. S.). Total division of median, 2-in. gap, sutured. Ulnar thinned at scar, but conducted F to above muscles. Wrapped in fat. *April.*—Discharged to London. *Nov.*—Reports no treatment, and no recovery.

SUMMARY.—(8 *months*) *No recovery.*

Case 47.—*March*, 1917.—Wounds of flexor surface of L elbow, and middle of L forearm. Brachial artery ligatured upper wound. Complete ulnar and doubtful median paralysis. *May.*—Complete ulnar paralysis hand only, partial median paralysis. *July.*—Healed. Fair power median forearm muscles, none in flexor longus pollicis, or in hand muscles. *Aug.*—OPERATION (H. S. S.). Median exposed in upper wound, and freed, surrounding scar tissue excised. Both nerves exposed in lower wound. Complete division of ulnar, with 2-in. gap, bridged by flap method. Median not obviously damaged, but did not conduct F. *Sept.*—Condition unaltered. *June*, 1918.—Doctor reports ulnar sensation recovered, except in phalanx of little finger. Movements of thumb improving.

SUMMARY.—(10 *months*) *Ulnar sensation recovered.*

Case 48.—*July*, 1916.—Inner side R arm above elbow blown away. Brachial artery tied in France. *Aug.*—No V P in median and ulnar nerves; complete R D in muscles. *Nov.*—OPERATION (H. S. S.). Nerves exposed. Complete division found, with 3 in.-gap. As this could not be closed, 3 in. of humerus were excised, the resect being used as a medullary peg. Median and ulnar nerves sutured directly, but not internal cutaneous. (*Figs.* 285, 286.) *April*, 1917.—No change in anæsthesia. Slight V P in flexors and pronators. Pressure on ulnar nerve 3 in. below suture causes radiating pain in ulnar area of hand. *June.*—V P in all forearm muscles, median and ulnar. Pressure on median 4 in. above wrist and ulnar on wrist, causes characteristic radiating pain. *Sept.*—Good V P wrist and fingers. Pressure on median at wrist causes radiating pain. Sensation largely recovered. Forearm flexors react to F slightly. *Oct.*—Wool felt half-way down palm, pin to middle of second segments of fingers. Good reaction in forearm to F. Hand muscles as yet show no recovery. *Jan.*, 1918.—Protopathic recovery to ends of fingers. V P in all forearm muscles, none in hand. Fingers held in phalangeal flexion, but can be readily straightened.

SUMMARY.—(6 *months*) *Commencing recovery.* (8) *Advanced recovery, sensory and motor.* (12) *Complete recovery except in small muscles of hand. Full power in forearm.*

Case 49.—*July*, 1916.—Bullet perforated inner side R arm just below elbow. A week later, radial ligatured for hæmorrhage. *Aug.*—Slight V P in flexors of forearm. *Oct.*—Median and ulnar anæsthesia. Slight V P in all muscles of forearm and hand; hand muscles do not react to F. *Feb.*, 1917.—Condition unaltered. OPERATION (R. H. C.). Stimulation of ulnar and median nerves by F caused contraction of all forearm but no hand muscle. Nerves freed from dense scar tissue, and wrapped in fat. *April.*—Improved power in forearm muscles. *May.*—Discharged P U. *Nov.*—Reports complete recovery of sensation median area, none in ulnar, and recovery of power in flexor muscles. *June*, 1918.—Doctor states forearm less wasted. Interossei improving. Great improvement in flexion. Extension of wrist and fingers. All muscles, except interossei, respond to F.

SUMMARY.—(10 *months*) *Recovery of median sensation. Power in forearm muscles.* (16) *Complete recovery, except in small muscles of hand.*

Case 50.—*July*, 1916.—Bullet perforated inner side of R arm above elbow. At first partial median anæsthesia, severe pain in hand. As pain diminished, anæsthesia extended. *Sept.*—Complete paralysis, motor and sensory, median, ulnar, internal cutaneous. R D in all paralyzed muscles. *Nov.*—Slight V P in all forearm muscles, but R D in all. No recovery of sensation. *Feb.*, 1917.—No further improvement. OPERATION (H. S. S.). Ulnar and median embedded in dense mass of scar tissue. No conduction of F in ulnar. Median conducted F slightly to forearm muscles only. Excision suture of both, 2 in., with forward dislocation of ulnar. *July.*—Ulnar sensitive at elbow. Slight V P in flexors of forearm, median and ulnar. *Oct.*—Pin can be felt in palm as low as web. Some recovery to pin in dorsal branch of ulnar. Power improving. Pressure on ulnar at palm causes radiating pain in fingers. *Jan.*, 1918.—Sensation rapidly recovering. Good V P in all muscles of forearm. *March.*—V P in all muscles except thumb. Sensation recovered except in little finger.

SUMMARY.—(6 *months*) *Motor recovery in forearm.* (8) *Sensory recovery to web of fingers.* (12) *Recovery complete except in small muscles of hand.*

MEDIAN AND ULNAR NERVES (CASES NOT OPERATED).

Case 51.—*Jan.*, 1917.—Two large wounds inner side of R arm and forearm. Brachial artery tied. Median and ulnar paralysis. *April.*—Complete median and ulnar paralysis, with R D. *June.*—Transferred to Carlisle.

SUMMARY.—*Transferred without operation.*

Case 52.—*July*, 1916.—Bullet perforated R arm, just below elbow. Ligature of brachial. Painful median and ulnar anæsthesia, with paralysis in all muscles. *Nov.*—Forearm muscles react to F. R D in hand muscles. *March*, 1917.—V P in forearm muscles, and all muscles of hand except adductors of thumb. Sensation recovering. *May.*—Sensation almost entirely recovered. V P in all muscles. Reactions normal.

SUMMARY.—*Almost complete recovery* 10 *months after injury.*

MUSCULOSPIRAL NERVE (OPERATION CASES).

Case 53.—*May*, 1917.—Perforating wound outer side of upper arm below middle. Complete musculospiral paralysis, except triceps. *June.*—Anæsthesia external cutaneous, and radial area. R D in all paralyzed muscles. *Sept.*—OPERATION (R. H. C.). Nerve exposed in groove through posterior incision. 1¼ in. excised, and ends joined by direct suture. *Nov.*—No change. Reaction to G sluggish, but good volume, muscles in good condition. *June*, 1918.—Doctor states patient can flex and extend fingers and wrist slightly; grip greatly improved.

SUMMARY.—(9 *months*) *Recovery advanced.*

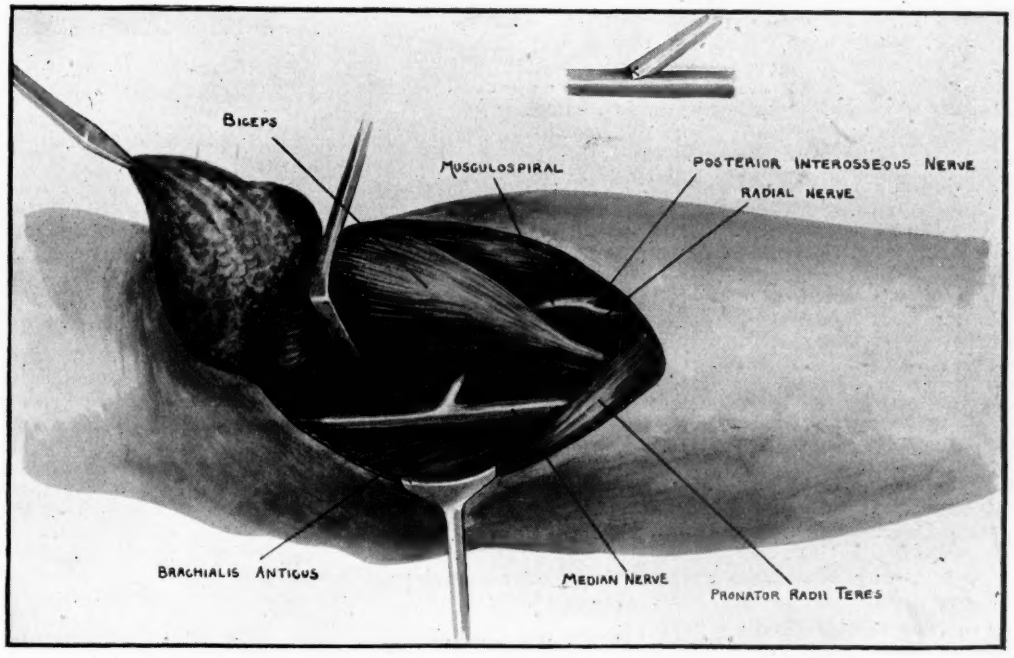


FIG. 287.—Anastomosis of paralyzed musculospiral with median. *Cases* 54, 56, 59.

Case 54.—*Sept.*, 1916.—Badly lacerated compound fracture upper third R humerus. Complete musculospiral paralysis, except long head of triceps. *March*, 1917.—Bone united with large mass of callus. Sinus led down to sequestra. To remove these, bone opened up freely, one side of cavity being completely removed. No V P in musculospiral below wound, and complete R D. *Oct.*—OPERATION (H. S. S.). Nerve exposed and traced to tunnel in bone, where both proximal and distal ends terminated in fibrous bands, with a gap of 3½ in. Lower end was therefore anastomosed to centre of front of median, fibres of which were here divided. (*Fig.* 287.) *Nov.*—Slight paresis of pronators. flexor carpi radialis, and sublimis. No loss of power in thumb muscles, no sensory loss. A little pain referred to middle fingers. *Jan.*, 1918.—Definite tingling in palm, on pressure over musculospiral 2 in. below anastomosis. *May.*—Tingling now felt from lower third of forearm. No V P or F response. *July.*—F response in extensors of wrist.

SUMMARY.—(4 *months*) *Nerve sensitive below suture.* (8) *Sensitive in lower third of forearm.* (10) *F response returned.*

Case 55.—*July*, 1916.—Fracture middle of L humerus. Wrist-drop. *Oct.*—Anæsthesia radial area on dorsum of hand. Complete paralysis, with R D of all musculospiral muscles except triceps. *Nov.*—OPERATION (H. S. S.). Nerve exposed, and found completely divided, ends being joined by fibrous tissue in tunnel of callus. Resection with direct suture. *April*, 1917.—Slight numbness in radial area; no definite anæsthesia; no motor recovery. *May.*—Slight power

in extensors of wrist. *June.*—Fair power in supinators and extensors of wrist, slight V P in extensor communis and thumb extensors. *Aug.*—V P extensor indicis. Reactions of all muscles weak to G, nil to F. *Sept.*—Extensor carpi ulnaris reacts to F. *Oct.*—Good V P in all muscles which react to F. Limb almost normal in appearance and power.

SUMMARY.—(6 *months*) *Slight power of extension of wrist.* (8) *Power in all extensors.* (10) *Reaction to F first obtained.* (12) *Complete recovery, return to duty.*

Case 56.—*June*, 1916.—Large wound back of R upper arm. Fractured humerus. *Sept.*—Bone united, wound still large. Doubtful V P triceps; complete loss, with R D, in all other musculospiral muscles. Wool anæsthesia external cutaneous and radial areas. *April*, 1917.—Triceps recovering. No reaction to G in extensors of forearm. External cutaneous recovered. Radial unchanged. *May.*—OPERATION (H. S. S.). Nerve exposed in axilla and beneath triceps. Branch to triceps intact. Main trunk fibrosed for 3 in., with end bulb. Direct suture considered impracticable. Nerve exposed through fresh incision under supinator longus, and median by horseshoe extension of incision. Musculospiral carried across arm between biceps and brachialis anticus, and implanted into median, antero-external fibres of which were cut. (*Fig.* 287.) Eight days later no loss of median power or sensation could be discovered. *Oct.*—No return of V P. Small area of radial anæsthesia. *Jan.*, 1918.—Tenderness to pressure on posterior interosseous 3 in. below elbow, tingling in median area of palm. Reactions brisk at motor points. *April.*—Synergic contraction of extensors on flexing fingers. *June.*—Grip powerful, and assisted by extensors, which have weak, independent V P, and react to F.

SUMMARY.—(8 *months*). *Nerve sensitive 3 in. below elbow.* (10) *Sensitive lower third of forearm. Slight power in supinator longus and radial extensors.* (12) *Strong synergic action of extensors of wrist, independent power improving.*

Case 57.—*July*, 1917.—Bullet pierced L arm, fracturing humerus below neck. Wrist-drop occurred at once. *Sept.*—Total musculospiral paralysis, excluding triceps. No reaction to F in paralyzed muscles, brisk response to G, marked galvanic tetanus. Partial anæsthesia on dorsum of thumb. *Oct.*—Typical R D in paralyzed muscles. OPERATION (H. S. S.). Nerve adherent to bony spur. Removal of spur exposed small cavity in bone, which was scraped out and filled with B.I.P.P. Upper end of nerve divided from scar, a branch to long head of triceps being inevitably divided at same time. Distal end in two portions and easily separated from scar. These two portions and nerve to triceps directly sutured to proximal end. Brachial artery involved in scar, and was ligatured during separation of nerve. *Jan.*, 1918.—No change. No power in triceps, which shows R D. *March.*—Weak V P in triceps, other muscles react briskly to G, not to F. *May.*—Distal tingling on pressure above external condyle.

SUMMARY.—(6 *months*) *Power in triceps. Nerve sensitive at elbow.*

Case 58.—*July*, 1916.—Large wound, antero-external aspect of R elbow, tissues destroyed down to bone. Complete musculospiral paralysis below wound. *March*, 1917.—Still complete paralysis, with R D. OPERATION (H. S. S.). Nerve found divided at bend of elbow, with large end bulb, and gap of 3 in. below as far as supinator brevis. Posterior interosseous exposed in supinator brevis, hard, fibrous, and wasted. No conduction to F. Muscles supplied by this nerve pale, and responded feebly to direct F. Bulb removed, end-to-end suture, with elbow flexed. *Oct.*—No definite V P. Reaction to G brisker and of better volume. *Feb.*, 1918.—Slight V P in extensor carpi ulnaris. *July.*—Fair power in extensors of wrist and fingers.

SUMMARY.—(10 *months*) *Slight power in extensor carpi ulnaris.* (16) *Recovery in all muscles.*

Case 59.—*Jan.*, 1915.—Wound L arm. Severe fractured humerus. Paralysis of musculospiral nerve. *Nov.*—OPERATION. 4 in. of nerve missing, graft of internal cutaneous introduced. *Jan.*, 1917.—No evidence of recovery. Total sensory loss in internal cutaneous and radial areas. Triceps normal, other muscles R D. No V P. OPERATION (H. S. S.). No trace of graft discovered. Distal end exposed, gave no reaction to F. Brought under biceps and implanted into median on anterior aspect, a third of the fibres being divided. (*Fig.* 287.) *Feb.*—Sensory loss in small median area. Loss of V P in flexor longus pollicis and opponens. All other median muscles intact. *July.*—Recovery of sensation in median area. Slight V P in flexor longus pollicis. *Jan.*, 1918.—No evidence of musculospiral recovery, though reactions to G somewhat brisk. Complete median recovery.

SUMMARY.—(12 *months*) *No recovery.*

Case 60.—*Nov.*, 1917.—Transverse wound back of L upper arm, near deltoid insertion. Wrist-drop. *Jan.*, 1918.—Paralysis of supinator longus, and extensors of forearm, with R D. Anæsthesia in an exceptionally large radial area. Paresis of median and ulnar muscles, but all have V P. *April.*—OPERATION (W. M.). *Resection suture.*

Transferred.

MUSCULOSPIRAL NERVE (CASES NOT OPERATED).

Case 61.—*Jan.*, 1917.—Wound L arm. Fracture lower end of humerus. Musculospiral paralysis. *May.*—Complete paralysis in forearm. Discharged to Ireland.

SUMMARY.—*Transferred without operation.*

Case 62.—*Sept.*, 1916.—Wound upper part of R arm. Fractured humerus. Musculospiral paralysis. *Feb.*, 1917.—V P in triceps, supinator longus, and long radial extensor; none in posterior interosseous. Incomplete R D in all except triceps. *July.*—Transferred to Cardiff.

SUMMARY.—*Transferred without operation.*

Case 63.—*Sep.*, 1916.—Fracture upper end L humerus. Musculospiral paralysis. *Feb.*, 1917.—Paralysis complete, except for triceps and supinator longus. *March.*—V P in radial extensors of wrist. R D and no V P in posterior interosseous muscles. *April.*—V P in extensor carpi ulnaris. *May.*—V P in extensor communis digitorum. *Aug.*—Complete recovery. Discharged to duty.

SUMMARY.—*Complete recovery* 11 *months after injury.*

Case 64.—*May*, 1917.—Wound R knee, and small wound outer side of R arm. Wrist-drop. *Sep.*—R D and no V P in musculospiral muscles below wound. *Nov.*—Has recovered fair V P. *March*, 1918.—Power much improved. Nil to F; G brisk at motor points. Slight numbness in radial area. *July.*—Complete recovery.

SUMMARY.—*Complete recovery* 14 *months after injury.*

Case 65.—*July*, 1916.—Two large septic wounds back of R upper arm. Musculospiral paralysis. *Aug.*—triceps reacts to F. R D in other muscles, with loss of V P. Sensory loss in musculospiral area on forearm. *Sept.*—V P extensors of wrist, thumb, index. V P in supinator longus and brevis. Nil to F in posterior interosseous. G brisk at motor points, sluggish over tendons. *Feb.*, 1917.—Power improving; all react to F. No loss of sensation.

SUMMARY.—*Advanced recovery* 7 *months after injury.*

Case 66.—*Aug.*, 1916.—Wound R arm. Fracture middle of humerus. Musculospiral paralysis. *Nov.*—Slight V P in triceps, and possibly supinator longus. R D and no V P in other muscles of group. *March*, 1917.—Recovering V P in all except deep extensors. *June.*—Fair power in all muscles.

SUMMARY.—*Advanced recovery* 10 *months after injury.*

Case 67.—*May*, 1917.—Two small punctured wounds upper part of L arm. Bruit over upper wound. Paresis of musculospiral. Immediate wrist-drop. *June.*—Small aneurysmal varix of superior profunda, slight numbness in radial area, and weakness of extensors; but all muscles react to F. *July.*—Power improving. Discharged to Australian hospital.

SUMMARY.—*Advanced recovery* 2 *months after injury.*

Case 68.—*June*, 1916.—Wound L arm. Fractured humerus. Wrist-drop. *July.*—Extensors of forearm react to F. *Aug.*—All muscles recovered V P. *Oct.*—Discharged with good power in all muscles.

SUMMARY.—*Recovery* 2 *months after injury.*

Case 69.—*July*, 1917.—Wound L arm. Fractured lower third humerus. Wrist-drop immediately. *Nov.*—Nearly healed, fracture united. Complete paralysis, with R D of musculospiral from supinator down. Radial anæsthesia to wool. *Jan.*, 1918.—Slight power radial extensors. Nil F. Loss to wool same area. Patient says he has more feeling. *April.*—Full power in all muscles, sensory loss as before.

SUMMARY.—*Complete recovery of power* 9 *months after injury.*

Case 70.—*April*, 1916.—Multiple wounds L forearm. Fracture radius and ulna, and musculospiral paralysis. *June.*—Complete paralysis below elbow, with R D, except that supinator longus reacts to F. *Oct.*—Slight recovery V P in extensors of forearm. Reactions brisker. *Dec.*—Complete recovery.

SUMMARY.—*Complete recovery* 8 *months after injury.*

Case 71.—*July*, 1916.—Wound L arm. Fracture upper third humerus. Complete loss of power in biceps, brachialis anticus, and all musculospiral muscles below triceps. *Aug.*—Paralysis and R D biceps and brachialis anticus. V P musculospiral group, though R D still persists. *Sept.*—Reactions in musculospiral group becoming normal. Biceps and brachialis anticus show R D and no V P. *Oct.*—OPERATION (H. S. S.). Musculocutaneous found divided and adherent to bone at point of entry to biceps. Resection suture. *Oct.*, 1917.—No recovery in musculocutaneous. Complete recovery musculospiral. Supinator longus so hypertrophied that flexion of elbow is normal.

SUMMARY.—*Complete recovery* 9 *months after injury.*

Case 72.—*July*, 1916.—Wound L arm, outer side above elbow. *Aug.*—R D and no V P in musculospiral muscles below point of injury. *Jan.*, 1917.—Recovering V P. R D still present. *Feb.*—Nerve conducts G, and muscles react briskly to G, but not to F. *March.*—Nerve conducts, and muscles react to F. V P good. *July.*—Complete recovery.

SUMMARY.—*Complete recovery* 12 *months after injury.*

Case 73.—*July*, 1916.—Small wound outer side L arm above elbow. Musculospiral paralysis *Sept.*—R D and no V P posterior interosseous. Supinator longus doubtful. *March*, 1917.—Weak V P extensors of wrist and fingers, not thumb. Electrical reactions unaltered. *June.*—

Little improvement. Slight power in extensor ossis metacarpi pollicis. Extensor muscles for most part react to F. *Dec.*—No improvement. *Jan.*, 1918.—Fair V P and F response, radius and ulnar extensors. No V P, and no F response communis, or short extensors.

SUMMARY.—*Poor recovery* 18 *months after injury.*

POSTERIOR INTEROSSEOUS NERVE (OPERATION CASES).

Case 74.—*April*, 1917.—Small perforating wound front of L elbow. Complete paralysis posterior interosseous. Perforating wound of R chest. *July.*—R D in posterior interosseous group and in extensors of wrist, and paralysis of all these muscles. *Sept.*—OPERATION (H. S. S.). Nerve explored. Complete fibrosis at origin of posterior interosseous. Nerve to extensor carpi radialis longior conducted F. 1¼ in. damaged nerve excised, with direct suture. Nerve reached in gap between extensor carpi radialis longus and supinator longus. *June*, 1918.—Report from doctor states that patient can extend wrist, but not fingers. Thinks he is improving.

Case 75.—*July* 1, 1916.—Bullet perforated L forearm transversely in front of bones. Wrist-drop. *July* 20.—Paralysis posterior interosseous group. All react to F except thumb extensors; and briskly to G. No anæsthesia. *Aug.*—R D in paralyzed muscles. *Oct.*—OPERATION (H. S. S.). Nerve exposed in supinator brevis. 1 in. densely fibrosed. Resected with direct suture. Did not conduct F. *April*, 1917.—Slight V P in extensors of thumb and extensor carpi ulnaris. All react briskly to G at motor points. *May.*—Fair V P in above muscles, slight V P in extensor communis. *July.*—Good V P in all muscles. Extensor communis and carpi ulnaris react to F, and briskly to G. Deep muscles sluggish. Discharged to duty.

SUMMARY.—(10 *months*) *Complete recovery.*

Case 76.—*July*, 1916.—Small wound back of R forearm. Extensors of thumb, and index paralyzed. *Nov.*—OPERATION (H. S. S.). Nerve exposed at point where it divided into several branches. Resection suture, with separate suture of each branch to proximal trunk. *May*, 1917.—No sign of recovery. Discharged P U.

POSTERIOR INTEROSSEOUS NERVE (CASES NOT OPERATED).

Case 77.—*June*, 1916.—Wound R elbow, fracture of humerus. Wrist-drop. *Aug.*—Complete paralysis, and R D in radial extensors and posterior interosseous muscles. *May*, 1917.—Nerve recovered, fair V P. *Sept.*—Complete recovery.

SUMMARY.—*Complete recovery* 13 *months after injury.*

Case 78.—*May*, 1917.—Wound L arm just above external condyle. Paralysis extensors of forearm. *June.*—Small healed wound just above L elbow. V P triceps, supinator doubtful, very feeble power in posterior interosseous muscles. Thumb extensors nil. No anæsthesia. F in triceps supinator longus only. G in paralyzed muscles fairly brisk. *Oct.*—V P supinator and radial extensor. No V P, R D posterior interosseous. *Dec.*—Posterior interosseous recovered. V P to all muscles. Nil to F. *Jan.*, 1918.—Good V P posterior interosseous. Numbness unchanged (radial area). *March.*—Perfect V P. Very slight numbness in radial area. Discharged to duty.

SUMMARY.—*Complete recovery* 10 *months after injury. Discharged to duty.*

Case 79.—*April*, 1917.—Large wound outer side upper L forearm. Fracture radius and ulna. Posterior interosseous paralysis. *May.*—Ulna plated in open wound. *July.*—Anæsthesia to pin in radial area. No V P in posterior interosseous or in radial extensors. *Sept.*—V P in radial extensors. No V P in posterior interosseous, and no reaction to F or G. Plate removed.

SUMMARY.—*Case unsuitable for operation. No recovery.*

BRACHIAL PLEXUS (OPERATION CASES).

Case 80.—*Jan.*, 1916.—Wound R axilla. Traumatic aneurysm axillary artery, which was ligatured. Extensive paralysis of arm followed, severe pain in hand and forearm. *Nov.*—Gross fixation of hand; has not responded to treatment. Pain present, but has gradually improved. Trophic changes very marked. Ulnar chiefly affected. OPERATION (H. S. S.). Nerves dissected out, both above and below clavicle, from dense scar tissue, and surrounded with fat. Nerves all reacted feebly to F. *Dec.*—Sensation recovering. V P in flexor carpi ulnaris. No pain. *June*, 1917.—Hand muscles recovering V P. Wool and pin felt everywhere, slightly blunted on ulnar border of little finger. Marked recovery in mobility of fingers and usefulness of hand.

SUMMARY.—(6 *months*) *Extensive recovery, sensory and motor.* (8) *Recovery almost complete.*

Case 81.—*July*, 1916.—Wound of R arm below shoulder. Fractured humerus. Arm felt dead below elbow at once. Next day intense pain hand and fingers. *Aug.*—Irregular hyperæsthesia and anæsthesia of hand. No V P in fingers. *Oct.*—Wasted, tremulous, purple hand. Drop-wrist. Pain shoots at night into ulnar fingers and thumb. Anæsthesia in these areas. *Oct.* 30.—Alcohol (5 min.) injected into upper and lower trunks above clavicle. Slight relief from pain followed for few days only. *Nov.*—Wound reopened. Injection of alcohol (30 min.) into all three trunks.

Pain reduced but not abolished. Hand held stiff and extended. Fingers became glazed, smallest movements cause great pain. *July*, 1917.—Entirely free from pain. Hand stiff, but healthy in appearance. Slight power in flexors of forearm. Sinus in upper arm still open. *Feb.*, 1918.—Fingers stiff and movements limited. Total paralysis of musculospiral. Sinus closed. *April.*—Operation (H. S. S.). Musculospiral sutured in axilla, with difficulty, over 2 in. gap. Nerve entirely destroyed.

SUMMARY.—*Slow but progressive recovery until* (18 *months*) *suture of musculospiral.*

Case 82.—*July*, 1916.—Wound below L clavicle, passing upwards and backwards. Small perforating wound back of L forearm in upper third. Complete musculospiral paralysis, with anæsthesia to outer side of hand and forearm. *Aug.*—Paralysis and R D in whole musculospiral group except supinator longus, which has slight V P. OPERATION (H. S. S.). Fragment of shell removed from behind middle trunk of plexus. *Sept.*—V P and response to F in triceps, radial extensors; R D in posterior interosseous group. *March*, 1917.—OPERATION in view of no further recovery. Posterior interosseous explored. No direct damage found, but nerve looked degenerate and did not conduct F.

SUMMARY.—(4 *months*) *Recovery of all put posterior interosseous group.*

Case 83.—*April*, 1917.—Punctured wound of L axilla. A fortnight later paralysis of musculospiral, and traumatic aneurysm axillary artery. This was excised on account of severe hæmorrhage. *July.*—Extensive plexus paralysis. Anæsthesia to elbow. Complete paralysis posterior cord and hand muscles. Weak V P in forearm. *Oct.*—Considerable sensory, but no motor recovery. *Nov.*—OPERATION (L. E. C. N.). Musculospiral and circumflex found completely divided, with end bulbs, and sutured. Median and ulnar freed from dense fibrous tissue. Both conducted F to forearm, but not to hand. Anæsthesia in ulnar, median, internal cutaneous, and radial area. *April*, 1918.—Sensory recovery in thumb and radial portion of hand. Complete paralysis of deltoid, triceps, and all musculospiral muscles. *June.*—Good V P in deltoid. Weak in supinator longus. None in triceps. Deltoid responds to F,; triceps brisk to G, nil to F. No further sensory recovery.

SUMMARY.—(8 *months*) *Sutured nerves recovering.*

Case 84.—*Sept.*, 1915.—Wound R shoulder. Aneurysm third part of axillary artery. *Oct.*—Complete median and musculospiral paralysis, with anæsthesia and R D. *Dec.*—OPERATION (L. E. C. N.). Artery ligatured above and below aneurysm, sac excised. *July*, 1916.—Triceps and median muscles of forearm react to F. *Sept.*—Can extend wrist slightly. V P in triceps. Anæsthesia median and radial areas. *Feb.*, 1917.—V P supinator longus and extensor muscles of forearm, and median flexors. *April.*—Power all muscles except opponens. Sensation recovering in fingers. Discharged P U. *Nov.*—Reports considerable sensory recovery. *June*, 1918.—Doctor reports pronation and supination half normal. Flexion of wrist normal. Extension $\frac{3}{4}$. Sensation of hand returning, particularly on ulnar side. Movements of fingers improving.

SUMMARY.—(6 *months*) *F reactions returning.* (10) *Power in triceps and extensors of wrist.* (14) *Power in all muscles of forearm.* (24) *Advanced recovery.*

Case 85.—*June*, 1915.—Perforating wound R axilla. *July.*—Total paralysis R arm. Biceps and extensors forearm respond to strong F. Other muscles no response to F or G. *Aug.*—Biceps and brachialis anticus show good V P. Triceps responds to strong F. Extensors forearm no response to F, faint to G. Severe aching pain in whole arm, complete sensory loss in forearm and hand. *Oct.*—No V P in any muscle in arm. Complete R D. Pain increasing. OPERATION (Maj. Nitch). Aneurysm first part of axillary dissected out, adherent to all nerves of plexus. Alcohol injected into nerves above lesion. No relief of pain followed. *Dec.*—Again explored. Musculocutaneous and inner head of median found divided, possibly in last exploration. Sutured directly. *July*, 1916.—V P in triceps, deltoid, supinator longus. Hyperæsthesia of arm to elbow, sensation returning in upper forearm. R D in all other muscles. *Dec.*—V P median flexors, and in all muscles of upper arm and supinator longus. Sensation recovered to wrist. No deep loss.

SUMMARY.—(8 *months*) *Power in triceps, deltoid, supinator longus.* (12) *Steady progressive recovery.*

Case 86.—*June*, 1917.—Small penetrating wound below R coracoid, metal lodged under scapula. *July.*—Intense pain in hand. Anæsthesia outer border of arm, forearm, and thumb. V P present in pectorals and spinati, deltoid doubtful, none in biceps, triceps, or other muscles of arm, forearm, or hand. All nerves react to F except musculospiral. Pain relieved by ionization of brachial nerves. *Aug.*—Ulnar and median muscles recovering. *Oct.*—Deltoid improving. No V P in biceps or musculospiral group. *Jan.*, 1918.—V P in biceps. Lesion now equivalent to complete musculospiral. OPERATION (H. S. S.). Plexus exposed below clavicle, pectoralis minor being divided. Plexus dissected from dense mass of scar tissue. Musculospiral found divided. Circumflex arose just above division, and had to be divided in exposure of proximal of posterior cord. Direct suture of musculospiral and circumflex posterior cord. *March.*—Complete paralysis in posterior cord. Weak V P in biceps. *April.*—Good V P in all ulnar and median muscles. Weak reaction to F, and doubtful V P in deltoid. *June.*—Good power in all muscles except those of posterior cord, which all react briskly to G. Nil to F. *Aug.*—V P in deltoid, which reacts to F. Triceps brisk to G and reacts to F.

SUMMARY.—(7) *Recovery of power in deltoid, triceps responds to F. Remainder of plexus has completely recovered.*

Case 87.—*July*, 1916.—Clean perforating wound below L axilla. No nerve lesion. *July* 14.—Traumatic aneurysm brachial artery. OPERATION (H. S. S.). Sac dissected out, vessel tied above and below. *Aug.*—Aching pain in head, worse at night. *Oct.*—Pain continuous. Extensive loss of sensation in region of ulnar areas. OPERATION (H. S. S.). Median and ulnar nerves dissected from dense fibrous tissue, and wrapped in fat. *Jan.*, 1917.—Pain entirely disappeared. Sensation recovering.

SUMMARY.—(4 *months*) *Extensive recovery.*

Case 88.—*April*, 1917.—Bullet traversed R posterior triangle, entrance in front just above clavicle, exit middle inner border of scapula. *May.*—Aching pain in hand, and tenderness of brachial plexus, with referred pain on pressure. No definite anæsthesia, but numbness of circumflex area and outer side of arm and forearm. No V P biceps, deltoid, supinator longus. Slight V P triceps and muscles of forearm. *June.*—Complete atrophy of deltoid and spinati, with loss of V P and R D. *July.*—OPERATION (H. S. S.). Plexus exposed above clavicle. Upper trunk scarred at junction of 5 and 6 cervical nerves. Freed from scar, and fibrous nodule in anterior aspect of trunk excised. Triceps alone reacted to F stimulation of this trunk. *Sept.*—V P in supinator longus hand and forearm good. No pain. *Dec.*—Slight V P in deltoid, biceps, brachialis anticus, supinator longus, but not sufficient to move elbow. No reaction to F. *Jan.*, 1918.—Power in these muscles improving, can flex elbow against gravity. *March.*—Good power in all muscles of arm, forearm, and hand. Movements slow.

SUMMARY.—(4 *months*) *Good power supinator longus hand and forearm.* (6) *Fair power in deltoid and flexors of elbow.* (8) *Good power in all muscles.*

Case 89.—*Sept.*, 1917.—Small wound of R neck, with fracture of 6th R transverse process. *Nov.*, 1917.—Intense causalgia palm of R hand, which is held rigidly semiflexed with thumb adducted into palm. Weak V P in all muscles, but slightest movements of arm cause intense pain. Flexor muscles of forearm respond feebly to F. Other muscles normal response. *Nov.* 11.—OPERATION (H. S. S.). Incision behind R sternomastoid. All cervical roots from 3 to 7, spinal accessory and phrenic nerves exposed in dissection. 5th root conducted normally to deltoid, biceps, supinator longus. 6th root gave no response. 7th root conducted forearm flexors, triceps, and extensors of forearm. 6th root swollen, and fragment of metal in contact with it. On attempting to dissect 6th root free, sac of small aneurysm of vertebral artery was torn, with profuse hæmorrhage. Artery tied close to origin, without result. Anterior portions of 5th and 6th transverse processes removed, and vessel tied above and below sac. Bleeding serious, and controlled with very great difficulty by this means. 5th cervical root injured in the operation. *Nov.* 23.—Pain entirely relieved. Movements of hand and flexors improved. Complete paralysis of 5th cervical nerve (biceps, deltoid, supinator longus, supra- and infra-spinati). *Jan.*, 1918.—V P in all muscles except biceps, deltoid, supinator longus, supra- and infra-spinati, which are wasted and show R D. Triceps very weak. Narrow area of anæsthesia radial border of forearm and hand. *April.*—Weak V P in deltoid and biceps. Good power in most other muscles. *May.*—Full V P in all muscles except supinator longus. Sensation recovered. *Aug.*—Good power in all muscles. No sensory loss.

SUMMARY (10 *months*) *Complete recovery.*

BRACHIAL PLEXUS (CASES NOT OPERATED).

Case 90.—*June*, 1916.—Wound above middle L clavicle. Empyema. *Sept.*—Paralysis and R D in supra- and infra-spinati, and deltoid, except for a few anterior fibres in last muscle. *Feb.*, 1917.—V P in deltoid. Discharged Carlisle.

SUMMARY.—*Deltoid recovered* 8 *months after injury.*

Case 91.—*Sept.*, 1916.—Wound of L axilla, followed by traumatic aneurysm, operation at station hospital two days later. *Dec.*—Wounds healed. Extensive paralysis brachial plexus. Deltoid shows fair power, triceps feeble, all other muscles in arm paralyzed. Anæsthesia below middle of forearm, except radial part of dorsum. Deltoid reaction normal. None in other muscles. *March*, 1917.—V P triceps, supinator longus, all extensors of wrist. No V P biceps flexors of wrist and fingers, extensors of fingers; supinator longus reacts to F. *April.*—V P in extensors of thumb. *July.*—Sensation returning. Almost complete recovery in biceps, supinator longus, extensors. No power in flexors of forearm or hand muscles. Ulnar sensitive at elbow. *Oct.*—Further recovery of sensation. V P in brachialis anticus. Great hypertrophy of supinator longus. *Feb.*, 1918.—Slight V P in flexors of wrist. Rubbing ulnar border of hand produces tingling.

SUMMARY.—*Very advanced recovery, except in hand,* 18 *months after injury.*

SCIATIC NERVE (OPERATION CASES).

Case 92.—*Sept.*, 1916.—Large wound R buttock. Sciatic paralysis. *Oct.*—V P in hamstrings. Complete paralysis other muscles, with R D. Small area of sciatic anæsthesia. *Feb.*, 1917.—OPERATION (H. S. S.) Complete division found in buttock. Direct suture over gap of 2 inches. *May.*—Discharged P U for treatment.

Case 93.—*April*, 1917.—Perforated wound R thigh. Complete sciatic paralysis. *May.*—No

V P. Complete R D in muscles supplied by external and internal popliteal. Corresponding sensory loss. *Sept.*—No improvement. OPERATION (H. S. S.). Complete lesion of sciatic nerve at middle of thigh. 1½ in. replaced by dense mass of fibrous tissue, 1 in. diameter. Resection with direct suture. No conduction to F. External and internal popliteal could be identified, and were correctly apposed.

Case 94.—*Sept.*, 1916.—Transverse wound back of L thigh, 4 in. above knee. *Oct.*—Two operations for secondary hæmorrhage, followed by drop-foot. *Jan.*, 1917.—External popliteal paralysis, with complete R D and anæsthesia. Weak V P in calf muscles. *Feb.*—OPERATION (H. S. S.) Sciatic freed from dense fibrous tissue; both divisions showed old bruising on surface. Internal popliteal reacted strongly to F. External popliteal in peronei only. Wrapped in fat. *April.*—Good power in peronei. Slight power in extensors. Discharged. *June.*—Sensation recovered in whole external popliteal area. Fair power in all muscles of leg.

SUMMARY.—(2 *months*) *Good power peronei.* (4) *Sensation recovered. Fair power in al muscles.*

Case 95.—*July*, 1916.—Wound near head of R fibula. Foot-drop. *Aug.*—Paralysis, with R D, anæsthesia in external popliteal. *Oct.*—OPERATION (L. E. C. N.). Complete division found. Bulb. Direct suture over 1-in. gap. Cargile membrane. *May*, 1917.—Doubtful V P in peronei. Sensation almost entirely recovered. Brisk reactions to G. Discharged. *June.*—Doctor reports complete recovery of movement and sensation.

SUMMARY.—(8 *months*) *Sensation complete, weak power peronei.* (10) *Complete recovery.*

Case 96.—*Sept.*, 1916.—Small perforating wound back of L thigh. Sciatic paralysis. *Oct.*—Paralysis with R D in internal popliteal. Weak V P in external popliteal muscles. Corresponding sensory loss. OPERATION (H. S. S.). Internal popliteal found divided just below bifurcation. Bulbous ends united by strand of fibrous tissue. Direct suture over 2-in. gap. *July*, 1918.—Doctor reports recovery of protopathic sensation and of muscular power.

SUMMARY.—(8 *months*) *Sensation and power recovering.*

Case 97.—*Sept.*, 1916.—Perforating wound above middle of back of R thigh. Immediate pain in sole, numbness of foot. *Oct.*—Causalgia in sole, numb to wool. Mixed hyperæsthesia in external popliteal area. Recovering V P. Paralysis and complete R D in external popliteal. Alcohol injection into nerve 3 in. above lesion. Both divisions conducted F before injection. *Nov.*—Wound suppurated, pain not relieved. *Dec.*—Complete paralysis whole sciatic distribution, with R D and anæsthesia. No pain. *Feb.*, 1917.—OPERATION (H. S. S.). Internal popliteal found completely fibrous. Two inches resected direct suture. External popliteal freed. Dense perineural adhesions found round injected portion of nerve. *June*, 1917.—Slight power in peronei. *July.*—Slight power extensors of toes. *Aug.*—Pin recovering external popliteal area. Power improving. *Sept.*—Slight V P in calf muscles. *Nov.*—Fair power in calf, no reaction to F. *Jan.*, 1918.—External popliteal reacts to F, and power is good. Pressure on post tibial 6 in. above ankle gives tingling in sole. Fair power in calf muscles. Discharged.

SUMMARY.—(4 *months*) *Slight power in peronei.* (6) *Slight power in extensors.* (8) *Slight power in calf.* (12) *Good power in all muscles.*

Case 98.—*July*, 1916.—Perforating wound R thigh just below buttock. Paralysis R leg. *Aug.*—Paralysis external popliteal, with R D and anæsthesia. No V P in internal popliteal, no sensory loss. *Nov.*—Calf muscles recovering. *Jan.*, 1917.—OPERATION (R. H. C.). External popliteal found completely divided, two end bulbs. Resection suture. Internal popliteal conducted F. *April.*—Discharged. *Nov.*—Reports considerable recovery in sensation and power. *June*, 1918.—Some further improvement.

SUMMARY.—(10 *months*) *Sensation and power recovering.*

Case 99.—*Aug.*, 1916.—Large portion middle of back of R thigh blown away. No V P below knee. External popliteal anæsthesia. Internal popliteal partial anæsthesia, and paræsthesia. *Jan.*, 1917.—Complete R D below knee. *Feb.*—OPERATION (H. S. S.). Internal popliteal almost entirely divided, though a few fibres traversed scar. External popliteal completely divided. Resection suture both nerves. *May.*—Pressure on external popliteal at neck of fibula gives radiating pain to foot. *Oct.*—Slight V P in peronei and calf muscles. *Jan.*, 1918.—Fair power in calf. None in peronei or anterior tibial group, though pressure on nerve produces radiating pain as before. Some sensory recovery. *June*, 1918.—Doctor reports slight improvement in power. Walks fairly well.

SUMMARY.—(4 *months*) *Nerve sensitive neck of fibula.* (8) *Slight power in peronei and calf muscles.* (10) *Good power in calf.* (11) *Continued improvement; walking well.*

Case 100.—*June*, 1916.—Wound through middle of R thigh. Foot-drop, with slight anæsthesia dorsum of foot and toes. Pain in ball of foot. *Nov.*—Fair V P internal popliteal. None in external popliteal. No pain. External popliteal anæsthesia. OPERATION (H. S. S.). External popliteal found completely divided. Sutured. Internal popliteal slightly nicked, but conducted F well. Was not touched. Both nerves wrapped in fat. *April*, 1917.—V P in peronei. sensory recovery in all but small area on dorsum of foot. *July.*—External popliteal paralysis again complete; patient has been wearing garter for elastic foot support, and pressure has injured the nerve. *Aug.*—V P present in all external popliteal muscles. No sensory recovery.

Jan., 1918.—Good V P. No sensory recovery in external popliteal area. *June.*—Reports can walk satisfactorily with an instrument.

SUMMARY.—(4 *months*) *Power in peronei and almost complete sensory recovery.* (8) *Secondary injury, complete paralysis.* (12) *Advanced motor but no sensory recovery.*

Case 101.—*March*, 1917.—Wound lower third of L thigh. Fractured femur. *Sept.*—Fracture united, wound not healed. Paralysis external popliteal, incomplete anæsthesia. Internal popliteal muscles weak and wasted, but slight V P. Sole hypersensitive. No reaction to F or G in any muscles of leg. *Dec.*—Wound healed. *Feb.*, 1918.—OPERATION (H. S. S.). External popliteal found divided. Direct suture. Internal popliteal freed. *June.*—Weak power in flexors of toes.

Case 102.—*April*, 1917.—Perforating wound upper part of back of R thigh, another outer side of popliteal space. Total sciatic paralysis of leg. *July.*—Complete paralysis external and internal popliteal, with R D anæsthesia. V P in hamstrings. *Sept.*—Paralysis as before, but pressure over nerve below wound causes tingling of leg and foot. *Nov.*—OPERATION (W. M.). Almost total division at level of lower border of gluteus maximus, with bulb on upper end. Resection suture over gap of 1¼ in. *April*, 1918.—No recovery V P or sensation, but muscles react briskly to G. Referred tingling obtained on pressure of external popliteal over fibula. *June.*—Referred tingling over dorsum of foot.

SUMMARY.—(8 *months*) *Sensation returning over dorsum of foot, but no voluntary power.*

Case 103.—*July*, 1916.—Small perforating wound L buttock. Anæsthesia back of thigh. No loss of power in limb. *Aug.*—Operation for hæmorrhage. Buttock opened up widely. Gluteal artery tied with great difficulty. *Sept.*—Paralysis of internal popliteal, with R D. *Nov.*—OPERATION (H. S. S.). Almost total scarring of internal popliteal found, small branch to hamstrings alone remaining: this was dissected away. Scar excised, and nerve sutured directly. *Dec.*—Transferred. *Nov.*, 1917.—No recovery. Stopped treatment since Aug. No work. *June*, 1918.—Reports referred tingling on pressure on calf. At work, but having no treatment.

SUMMARY.—(7 *months*) *Nerve sensitive in calf.*

Case 104.—*April*, 1917.—Small wounds outer side both knees. Foot-drop R side. Partial paralysis. *May.*—Slight numbness only dorsum R foot. V P and F present in peronei. Absent in extensors, with R D. *June* 19.—Numbness slightly improves. V P and reactions unchanged. Thickening felt on external popliteal behind biceps tendon. *June* 30.—OPERATION (H. S. S.). Nerve exposed, at emergence from cover of biceps tendon. Damage partial. Nerve split longitudinally into posterior external part (conducting F to peronei) and anterior inferior part (not conducting) of which ⅞ in. was resected, with end-to-end suture. Fat sleeve. *Sept.*, 1917.—No V P in peronei. Nil to F, moderately brisk to G. Other muscles R D. *Jan.*, 1918.—Fair V P in peronei returned in last few weeks. Nil F. No V P anterior tibial.

Case 105.—*July*, 1917.—Perforated wound behind outer side of R knee. Sciatic paralysis. *Aug.*—Complete external, partial internal popliteal anæsthesia. No V P in either, but spontaneous, painful, cramp-like movements in flexors of toes. Internal popliteal conducts F, and its muscles react. None in external popliteal. *Sept.* 18.—Cramp-like pains, but no spontaneous movements. Complete sciatic anæsthesia. Slight power internal popliteal, none external. *Sept.* 21.—OPERATION (H. S. S.) Explored popliteal space. Internal popliteal slightly constricted by fibrous band. Conducted F, and abnormally irritable to mechanical stimuli. External popliteal marked bulbous thickening. No conduction. Excision suture. *May*, 1918.—Fair power calf muscles, no V P in extensors, which react briskly to G, not to F. Referred tingling on pressure over neck of fibula. *June.*—Pin returned in upper third. Brush in upper third external popliteal area. Sensation completely recovered in internal popliteal area. *Aug.*—Fair V P external popliteal group, but no further sensory recovery.

SUMMARY.—(8 *months*) *Recovery, motor and sensory, internal popliteal. Sensory only external popliteal.* (11) *Motor recovery external popliteal.*

Case 106.—*June*, 1916.—Wound lower third of L thigh. Foot-drop. *July.*—Complete paralysis internal and external popliteal, with R D and sensory loss. *Nov.*—OPERATION (H. S. S.). Sciatic found completely divided, with large bulbous end. Excision and suture over 3-in. gap. Fat sleeve. *April*, 1917.—Complete sensory loss in sciatic area. Trophic ulcer of great toe. *July.*—V P in gastrocnemii, tibialis posticus, and peronei. Some sensory recovery upper peronei area. Ulcer healed. *Sept.*—V P all calf muscles. Fair V P peronei and tibialis anticus. No further sensory recovery.

SUMMARY.—(8 *months*) *Power in muscles of calf and peronei.* (10) *Fair power in all muscles.* (12) *Almost complete motor, but no sensory recovery.*

Case 107.—*June*, 1917.—Wound R leg, outer side below knee. *July.*—Anæsthesia external popliteal. Slight V P external popliteal muscles. Fairly brisk reaction to G. *Aug.*—Power improving. *Jan.*, 1918.—Fair power all muscles. No sensory recovery. *April.*—Pin produces radiating tingling in upper half of affected area. Tingling also produced by pressure on nerve below scar. V P in extensor longus hallucis and tibialis anticus only. No response to F. *May.*—OPERATION (L. E. C. N.). Neurolysis. Perineural adhesions only. *June.*—Sensation recovering on dorsum of foot. Weak V P in all extensors. None in peronei.

SUMMARY.—(1 *month*) *Definite recovery in sensation and power.*

SCIATIC NERVE (CASES NOT OPERATED).

Case 108.—*April*, 1917.—Perforating wound back of R thigh. Internal popliteal paresis. Pain in sole, anæsthesia to pin. Wasting and weakness of calf. No power in tibialis anticus or flexors of toes. *July.*—Pain improved. Slight power in gastrocnemii. No power, and R D in other muscles of calf. *Jan.*, 1918.—Fair power in gastrocnemii. No change in sensation. Discharged.

SUMMARY.—*Recovery of power, not of sensation, 9 months after injury.*

Case 109.—*Sept.*, 1916.—Wound L thigh. Fractured femur. No nerve lesion noticed. *April*, 1917.—Complete paralysis of L sciatic, with R D and anæsthesia. Onset gradual for last two months. There have been several operations for sequestrotomy. *Aug.*—Transferred.

SUMMARY.—*Transferred without operation.*

Case 110.—*Jan.*, 1917.—Wound upper third L thigh. Fractured femur. *Sept.*—Anæsthesia complete sciatic area, slight V P peronei. None in other muscles. No reaction to F or G. Wasting of leg severe. Nutrition bad. *April*, 1918.—Fair power in all muscles of leg. Slight return of sensation on outer side. *May.*—Sensation dorsum of foot completely recovered. Still complete anæsthesia of sole. Good power extensor muscles. Very weak in flexor. *June.*—Sensation recovered in whole of external popliteal area. Fair power in all muscles of leg.

SUMMARY.—*Fair recovery of power in all muscles, and of sensation, except in sole of foot, 18 months after injury.*

Case 111.—*Feb.*, 1917.—Large wound inner side of L thigh, high up. *March.*—Secondary hæmorrhage. Ligature of branches of profunda. Foot-drop followed. *June.*—Wound healed. Paralysis tibialis anticus and extensor longus hallucis, with R D. V P peronei and extensor longus digitorum. External popliteal anæsthesia. *Aug.*—Slight V P in paralyzed muscles. Sensation recovering. *Oct.*—V P much improved. *Jan.*, 1918.—Fair power in all muscles, except tibialis anticus. Discharged P U.

SUMMARY.—*Fair recovery, except tibialis anticus, 11 months after injury.*

Case 112.—*July*, 1917.—Large wound inner aspect of thigh above knee. Very weak power all leg muscles. Anæsthesia small sciatic area. *Aug.*—Anæsthesia outer side of sole only. External popliteal recovering V P. Very slight V P internal popliteal group, with complete R D. *Oct.*—Fair power in external popliteal. Complete paralysis of internal popliteal, with painful anæsthesia of sole. Marked trophic changes in skin of foot. Transferred.

SUMMARY.—*External popliteal recovered 3 months after injury. Transferred without operation.*

Case 113.—*April*, 1916.—Wound R thigh. Fractured femur. *Oct.*—Weakness posterior tibial group, calf tender, mixed hyperæsthesia and anæsthesia of sole. Partial R D in calf muscles. *Jan.*, 1917.—Completely recovered.

SUMMARY.—*Complete recovery 9 months after injury.*

Case 114.—*Aug.*, 1916.—Large wound back of upper R thigh. Fractured femur. *Jan.*, 1917.—Paralysis of anterior tibial muscles, with R D. No sensory loss. Transferred.

SUMMARY.—*Transferred without operation.*

Case 115.—*April*, 1917.—Wound L buttock. *May.*—Large abscess in buttock opened. Foot-drop noticed few days later. *June.*—Incomplete internal popliteal paralysis, small area of anæsthesia. Loss of power in extensors of foot, which give R D. *Sept.*—Recovering power, R D still present in extensors. *Feb.*, 1918.—Complete recovery. V P and sensation.

SUMMARY.—*Complete recovery 9 months after injury.*

Case 116.—*July*, 1916.—Perforating wound L buttock. Sciatic paralysis. *Sept.*—Complete sciatic paralysis below knee, with R D, and anæsthesia. Refused operation. Discharged.

SUMMARY.—*Discharged without operation.*

Case 117.—*July*, 1916.—Small wound over head of L fibula. Foot-drop. *Aug.*—Numbness in external popliteal area. Muscles paralyzed, but reactions normal. *Sept.*—V P returning. *Dec.*—Complete recovery.

SUMMARY.—*Complete recovery 5 months after injury.*

Case 118.—*April*, 1916.—Wound L buttock. Foot-drop. *July.*—External popliteal paralysis, with R D. *Oct.*—No return of V P. Reaction of peronei to G brisk. *July*, 1917.—V P in peronei. Paralysis and R D of other muscles. Sensory loss limited to dorsum of foot. Transferred.

SUMMARY.—*Recovery of peronei only 3 months after injury.*

Case 119.—*Aug.*, 1917.—Perforating wound L leg, just below knee. Severe pain in sole. *Sept.*—Intense causalgia of sole, without sensory loss. *Oct.*—Greatly improved. Transferred.

SUMMARY.—*Much improved 2 months after injury.*

Case 120.—*June*, 1916.—Perforating wound back of R thigh just above knee. Foot-drop. *Aug.*—Paralysis external popliteal, with R D and anæsthesia. *Sept.*—Muscles recovering. *Nov.*—Fair V P. Transferred.

SUMMARY.—*Fair recovery 5 months after injury.*

Case 121.—*Dec.*, 1916.—Perforating wound back of upper L thigh. *Jan.*, 1917.—Weak V P all muscles except tibialis anticus, which shows R D. Small area of sensory loss in sole. Tenderness in course of nerves. *March.*—Transferred.

SUMMARY.—*Transferred without operation.*

Case 122.—*Sept.*, 1915.—Wound L thigh in lower third. Fractured femur. *Nov.*—Bone united. *Feb.*, 1916.—External popliteal paralysis, with R D and anæsthesia. *May.*—Slight V P. Sensation recovering. *July.*—Power improving. No sensory loss. *Aug.*—Complete recovery.

SUMMARY.—*Complete recovery* 11 *months after injury.*

BIBLIOGRAPHY.

Monographs.

SHERREN, *Injuries of Nerves*, London, 1908.
STEWART AND EVANS, *Nerve Injuries and their Treatment*, 1916.
ATHANASSIO-BENISTY, *Clinical Forms of Nerve Lesions. Treatment and Repair of Nerve Lesions. Military Medical Manuals*, 1918.
TINEL, *Nerve Wounds, Eng. Trans.*, London, 1917.

General Articles.

CLARKE, *Bristol Med.-Chir. Jour.*, 1917, xxxv., 61.
CUMSTEN, *Dublin Jour. Med. Sci.*, 1917, cxliv, 137.
CUTLER, *Boston Med. and Surg. Jour.*, 1916, clxxiv, 305.
EVE AND WOODS, *Lancet*, 1915, ii, 1021.
FISCHER, *Ann. Surg.*, 1917, lxv, 56.
FRAZIER, *Surg. Gyn. and Obst.*, 1917, xxiv, 147.
JONES, R., *Brit. Med. Jour.*, 1916, i, 641.
LEWIS, *Surg.-Clin. Chicago*, 1917, i, 103.
MOYNIHAN, *Brit. Med. Jour.*, 1917, ii, 571.
OWEN, *Med. Jour. Australia*, Sydney, 1917, ii, 389.
PORTER, *Surg. Gyn. and Obst.*, 1917, xxiv, 144.
SACHS, *St. Paul. Med. Jour.*, 1917, xix, 165.
SOUTTAR, *Med. Review*, 1914, xvii, 5, 227; *Clin. Jour.*, 1914, xliii, ii, 161; *Brit. Med. Jour.* 1917, ii, 817.
STOOKEY, *Surg. Gyn. and Obst.*, 1916, xxiii, 639.
TROTTER, *Lancet*, 1915, ii, 1023.
WHITE, *Brit. Med. Jour.*, 1917, i, 388.
CHEVRIER, *Bull. et Mém. Soc. de Chir. de Paris*, 1917, n.s., xlii, 1056, 1983.
CHIRAY AND ROGER, *Bull. et Mém. Soc. Méd. des Hôp. de Paris*, 1916, 3, s.
DUMAS, *Bull. et Mém. Soc. de Chir. de Paris*, 1917, n.s., xliii, 1184.
BASSET, *Rev. de Chir.*, 1916, xxxv, 609, 754.
BORCHARDT AND VON EISELSBERG, *Beitr. f. klin. Chir.*, 1916, ci, 53.
HEILE AND HEZEL, *Ibid.*, 1916, xcvi, 299.
HOFFMEISTER, VON, *Ibid.*, 1916, xcvi, 329.
LORENTZ, *Ibid.*, 1916, c, 248.
MAUSS AND KRUGER, *Ibid.*, 1917, cviii, 143.
RAUSCHBERG, *Ibid.*, 1916, ci, 521.
THOLE, *Ibid.*, 1916, xcviii, 131.
WILMS, *Ibid.*, 1916, xcviii, 733.
STOFFEL, *Arch. f. Psychiat.*, 1916, 56, 360.

General Operative Technique.

SMITH, A., *Brit. Med. Jour.*, 1917, i, 861.
HUBER, *Jour. Lab. and Clin. M.*, St. Louis, 1916–1917, ii, 837.
BONNET, *Lyon Chirurg.*, 1916, xiii, 529.
MÜLLER, *Beitr. f. klin. Chir.*, 1917, cv (Kriegschir. Hefte vii), 651.
EDEN, *Arch. f. klin. Chir., Berlin*, 1917, cviii, 344; *Zentralbl. f. Chir.*, 1916, xliii, 600; *Ibid.*, 1917, xliv. 138.
STOFFEL, *Deut. med. Woch.*, 1915, xli, 1243.
MORO, *Deut. Zeits. f. Chir.*, 1916, cxxxviii, 264.

Special Technique of Anastomosis, Grafting, etc.

GERSTER AND CUNNINGHAM, *Med. Rec.*, New York, 1917, xcii, 223.
SICARD AND ROGER, *Marseille méd.*, 1916, liii, 129.
INGEBRIGTSEN, *Lyon Chir.*, 1916, xiii, 828.
KOLB, *Lyon Chir.*, 1916, 115, 423.
HAYWARD, *Zentralb.*, 1917, xliv. 263.

Experimental.

LEWIS AND KIRK, *Trans. Amer. Surg. Assoc.*, Philadelphia, 1916, 34, 485; *Jour. Amer. Med. Assoc.* 1915, 65, 486.
KENNEDY, *Phil. Trans. Roy. Soc.*, B. v, 202, p. 93; *Ibid.*, 205, p. 27.
STEINDLER, *Amer. Jour. Orthop. Surg.*, Boston, 1916, xiv, 707.
DUROUX AND COUVREUR, *Presse Méd., Paris*, 1916, xxiv, 572 *Rev. de Chir.*, 1917, liii, 11 and 12, 491.
STRACKER, *Zentralbl.*, 1916, xliii, 985.

Internal Structure of Nerves.

LANGLEY AND HASHIMOTO, *Jour. Physiol.*, London, 1917, li, 318.
HEINEMANN, *Archiv. f. klin. Chir.*, 1916, cviii, 107; *Ibid.*, 1917, cix, 121.

Reports of Conferences.

"Alder Hey," *Brit. Med. Jour.*, 1918, Mar. 30.
"Deutschen Ortho. Gesellschaft," *Zeits. f. Orth. Chir.*, 1916, xxxvi, 303.

SUTURE OF THE MUSCULOSPIRAL NERVE: THREE CASES.

By Captain GWYNNE WILLIAMS, R.A.M.C. (T.), London.

The following cases show the completeness with which motor recovery takes place after suture of the musculospiral nerve, and accord with the general impression as to the results of suture of this particular nerve. They are brought forward because they show the rate of recovery of the nerve and—by the order in which recovery of the muscles takes place—emphasize the progressive down-growth of the axis-cylinder. They are also put forth as offering a hypothesis to explain the difference in the results of suture in the musculospiral as opposed to other nerves.

The technique of the operation has in every case been quite simple, the nerve ends being brought together without any tension by a single catgut suture through the substance of the nerve. The line of suture has been wrapped round with subcutaneous fat. Precautions were taken to prevent any tension on the union until a month had elapsed. In all cases the muscles paralyzed were relaxed by an extension splint. In *Cases* 1 and 3 the fingers were kept extended from the first; but in *Case* 2 this was not done until the radial extensors had recovered; this helped to prevent the stiffness of the metacarpophalangeal joints, which is liable to occur as a result of prolonged extension of the fingers even when massage and movements are used daily. In *Case* 1 no other treatment was carried out, but in *Cases* 2 and 3 massage and galvanism were employed.

Case 1.—J. M., age 15, came under my care at University College Hospital, on Oct. 2, 1916, having cut his right arm just above the elbow-joint a month before. The wound was not quite healed, and there was complete musculospiral paralysis. The muscles were relaxed by an extension splint, but no recovery having taken place by Dec. 24, 1916, the nerve was explored.

Operation.—The ends of the nerve were separated by about one inch; they were freshened, and sutured with catgut, the line of suture being wrapped in subcutaneous fat.

The radial extensors recovered by April 12, 1917. I did not see the patient again until May 14, when the extensors of the fingers had recovered. On June 10 the extensor longus pollicis showed definite voluntary movements. The after-treatment consisted entirely of relaxation, since the patient was unable to attend for massage and galvanism.

Case 2.—B. Gunshot wound, March 23, 1917, involving the right musculospiral in the middle of the upper arm. The wound took some time to heal.

Operation.—Sept. 3. The nerve was found to be completely interrupted; both ends were freshened, and sutured with catgut, the line of suture being wrapped in subcutaneous fat.

The patient was not seen by me for some time, but says that he noticed recovery of the wrist-drop at the end of Feb., 1918. I saw him on March 4, and the radial extensors had recovered. On May 7 I received a report from Dr. Murray Levick that there was voluntary movement in the extensor communis digitorum and the extensor ossis metacarpi pollicis, but not in the extensor longus pollicis. On June 25, the latter muscle showed definite voluntary movement, but was not very strong. The after-treatment consisted of relaxation, massage, and galvanism.

Case 3.—J. S. M. Gunshot wound, Nov. 5, 1916, involving the musculospiral and musculocutaneous nerves at the outlet of the axilla on the left side. No suppuration.

Operation.—Jan. 6, 1917. The musculospiral was found to be completely interrupted by scar tissue; this was excised and the nerve sutured with catgut, the suture line being covered by a sheath of subcutaneous fat. The musculocutaneous was fixed by scar tissue, from which it was released, and the nerve wrapped in fat.

Movement in the biceps was first noticed on Feb. 22, 1917. In July, movement was suspected in the extensors of the wrist, and by the middle of September the hand could be supported, the extensor carpi radialis longior acting well. Extension of the little finger was noticed by Dec. 15; by Christmas the middle and ring fingers had recovered, and the index began to move about Jan. 16, i.e., a year after the operation. At the end of February there was a faint sign of movement in the extensor longus pollicis.

These facts as to recovery have been sent me by the patient from Australia; I have not seen them myself. The treatment was relaxation, massage, and galvanism.

It will be seen that recovery took place most quickly in *Case* 1, where the lesion was most peripheral, and that it was slower when the lesion was higher up. Thus the distance

of the line of suture from the elbow-joint, which corresponds roughly with the entrance of the branches into the radial extensors, was in *Case* 1 one inch, in *Case* 2 three inches, and in *Case* 3 seven inches, while recovery was noticed in these muscles in three and a half, six, and eight months respectively.

The next group of muscles to show recovery is the extensor communis digitorum, which the posterior interosseous nerve supplies immediately it has passed through the supinator brevis ; the times of recovery in this muscle group being five, eight, and twelve months. The last muscle to recover in each case was the extensor longus pollicis, in six, ten, and fourteen months respectively ; the nerve to this muscle is a long branch which enters the muscle about 5 in. distal to the elbow-joint.

Circumstances have necessarily rendered any more exact investigation of these cases difficult ; but the facts that have been presented show that recovery in any muscle is proportional to the distance of the lesion from the entry of the nerve into the muscle, and that the rate of growth of the axis-cylinder is about one inch in a month.

These three are the only cases of suture of the musculospiral nerve which I have been able to follow up in any way, and at first I was surprised at the completeness of their recovery, since there was no difference in the technique of the operation which was in any way likely to account for their success. Secondary suture of a nerve has always been regarded as unsatisfactory, and it seemed extraordinary that three consecutive cases should succeed. Reports of cases from other sources soon showed that suture of the musculospiral nerve gave very satisfactory results, so there must be some reason why the musculospiral nerve differs from other trunks such as the median and ulnar, where the recovery is very seldom complete. The only difference in the after-treatment usually carried out was that in the case of the ulnar and median it was very difficult to relax the muscles of the hand satisfactorily ; I tried various devices, but without success.

I therefore conclude that it must be the composition of the nerve that made the difference. The musculospiral trunk is almost entirely motor, the sensory distribution being not only small in area, but the area is, relative to the median and ulnar, of slight importance, so that the sensory nerve fibres are probably very few.

Any given axis-cylinder starting out from the upper end of the divided musculospiral nerve is almost certain to find its way down a motor path ; whereas with a mixed nerve, such as the ulnar, if we presume that the motor and sensory fibres are equal in number, the chances of a motor or sensory fibre finding its proper destination are about 50 per cent. There is no evidence that a motor fibre can pick out a motor path, or a sensory fibre a sensory path, and it would be expected that each fibre would take the path that was nearest. The deduction from this would be that a purely motor nerve or a purely sensory nerve should recover almost completely after a satisfactory suture, and in a mixed nerve the recovery might reach completeness if the approximation of the sections of the nerve was topographically accurate ; but unless this rather improbable condition of affairs was brought about, the sensory and motor recovery would both be partial.

Further, it might be said that if the suture of a purely motor nerve fails on one occasion, there seems no reason why it should not be undertaken again, unless it can be shown that there is a time limit after which the axis-cylinders will not grow down the nerve peripheral to the section. The results in a mixed nerve might be improved if it were possible, by knowledge of the topographical arrangement of the various nerve bundles in a trunk, to approximate the ends more accurately : it is possible to do this roughly in the upper part of the sciatic, but it is doubtful if it could be done in the median or ulnar, displaced as they frequently are by dense scar tissue.

The proof of this hypothesis would require an extensive series of observations on the relative motor and sensory composition of nerve trunks and the results of suture. Light would be thrown on the question by cases of suture of the facial and hypoglossal nerves. If shown to be true, it would be an important factor in determining the prognosis of nerve injuries.

I have to thank Colonel Bruce Porter for permission to publish *Cases* 2 and 3, which came under my observation at the 3rd London General Hospital.

SOME NOTES ON OPERATIVE PROCEDURE IN NERVE INJURIES.

By ROBERT KENNEDY, Glasgow.

In operations for the restoration of damaged nerves there are many conditions which must be present before a successful result can be looked for. Where there is evidence of damage to a nerve trunk, and an open wound or a septic sinus exists, the first step is to get the wound or sinus healed by ordinary surgical treatment. After the part is healed completely, and a sufficient time has elapsed for the scar to be safely dealt with, the question of operation may be considered.

When the time for operation arrives, there are certain conditions which must be observed before a successful result may be prognosed. Thus, in the case of the nerve having been severed, it is necessary to find the two separate segments. These again must be healthy or undamaged by inflammatory processes, excepting in so far as the ends are affected by scar formation. The exposure of the nerve segments should be made above and below the seat of injury, in accordance with the anatomical indications. After the central and peripheral segments have been found, they should be traced downwards and upwards respectively towards the seat of injury. Any attempt to cut directly into the damaged part is apt to lead to a long and futile search for the nerve ends. Cutaneous scars over the seat of injury of the nerve should be removed if possible by joining the two incisions made above and below by an elliptical incision encircling the scar, so as to effect the removal of the cutaneous along with the underlying scar.

In the vast majority of cases both segments of the nerve trunks when exposed are found to have a greater diameter than the nerve when normal. Usually this need give no concern—the thickening is due to œdema of the nerve trunk, and does not appear to affect the result. Certain thickenings of the nerve are, however, of a different nature, and have a serious effect on the outlook. The nerve trunk may be found inflamed, appearing dusky-red with dilated vessels, and this condition is associated with pain of a very severe nature. In such cases the best treatment consists of incisions into the thickened and inflamed trunk, made in a longitudinal direction to avoid injury to the nerve fibres. Should the trunk have been extensively damaged, and be now found thickened with scar formation, the prospects of a satisfactory result are extremely bad. These cases, however, are very exceptional, and in the majority the two segments are all right except at the seat of section. As a rule there is practically no difference in the thickness of the central and peripheral trunks.

When the nerve ends have been dissected out, they may be found in various conditions. The severance may have been complete, with no reunion. Both ends may present bulbs, that on the central end being usually the larger. Both ends may be without bulbs, but terminate in tapering ends involved in scar. Sometimes the central end presents a bulb and the peripheral a tapering termination. Sometimes, again, a kind of reunion has been effected between the two ends; this may occur as a strand of much greater tenuity than the nerve, or it may present a swelling considerably thicker than the nerve. Sometimes two nerves in close approximation have been divided, and the ends have united in a cross—or more frequently one central end has become joined to the peripheral end of the other nerve, the two remaining ends being ununited. A nerve and tendon may have been simultaneously severed, and the central end of the nerve be found to have united firmly with the peripheral end of the tendon, or vice versa.

In order to test the conductivity of the nerve, an electrical interrupted current may now be applied to the exposed nerve trunk by a sterilizable electrode. The application should be made as soon as the nerve is exposed, before any manipulation of it has taken place, and may be repeated from time to time as different parts are brought into view. The presence of conductivity is shown by contraction of the muscles supplied by the nerve. When the entire distribution of the nerve trunk has been found to be affected before the operation, it is very seldom that the electrical stimuli produce any muscular contractions; but in certain cases where the trunk has only been partially damaged, or reunion has been partially effected, it may serve to show to what extent the nerve is conducting. The current, to begin with, should be the smallest necessary to evoke a contraction; and it will be found that the nerve trunk, when irritable, can be stimulated at different points in the circumference, with different contractions resulting, the fasciculi supplying different groups of muscles being thus capable of being separately stimulated by a current not strong enough to stimulate the entire trunk. Before being applied to the nerve, the electrode should be tested on an exposed muscle in the vicinity in order to see the amount of current passing.

Before dealing with the ends of the severed nerve, it is necessary to pay attention to the surroundings of the nerve trunk. If these consist of dense scar, the scar masses must be cut away so as to leave normal tissue for the sutured nerve to lie in. Any neglect of this will end in failure; and should it be impossible to leave the nerve in healthy surroundings, a bad prognosis should be given. The same applies in the case of a nerve damaged in a part which has dense surroundings naturally, being confined in a narrow space. The most frequently occurring example of this is the ulnar nerve, when damaged behind the elbow, where it is lodged behind the internal epicondyle in a sulcus having for its boundaries the internal epicondyle and the olecranon process of the ulna. In this case it is probably impossible to get a satisfactory result unless the nerve is dislodged entirely from its position behind the epicondyle and fixed in front of the epicondyle and under cover of the humeral origin of the flexor carpi ulnaris where it is not confined by bony surroundings. The reason is that the enlargement which forms at the seat of suture compresses itself against the rigid boundaries of the sulcus and thus prevents conductivity

Where the loss of conductivity has been due, not to section, but to compression by cicatricial tissue or otherwise, attention must be directed entirely to the surroundings of the nerve, and on dissecting out the compressed trunk and ascertaining that it is intact, it only remains to dissect the cicatricial tissue away; the removal must be thoroughly done, otherwise recurrence of the compression will probably take place. When this is not possible for any reason, the prognosis is not good. In some cases the compression has been so severe that the nerve on removal of the scar shows a constriction over the entire extent of the compression; at other times the compressing ring has been so narrow that a furrow surrounding the nerve is all that shows the site of the compression on removal of the cicatrix. Should the perineurium be intact, such compression furrows or constriction do not call for excision, for the nerve will recover quite well. The constriction is not really so deep as it appears, owing to the œdematous condition of the nerve trunk above and below, which has not been under compression.

The next step is to determine the possibility of getting the segments to meet. This should be done before the nerve ends are prepared for suture, as otherwise the manipulation necessary to make them meet might so damage the freshly prepared ends as to endanger the result. At times they meet quite easily, but in other cases it is quite impossible to get them to do so. If the nerve has simply been shot through with a bullet, there is no difficulty; the ends may have retracted some distance, but this can be overcome. In other cases, however, such as shell wounds where a large piece of the nerve has been shot away, or where a septic condition has resulted in the sloughing of a large piece of the nerve, it may be impossible to bring the ends together.

If the ends do not come into apposition easily, various procedures may be adopted. Care should be taken, first of all, to see that the segments of the nerve trunk are not caught in a cicatrix further up, or down; this is often the cause of the difficulty in

making the ends meet, and when this cicatrix is cut, contact is easily made. Should this not be the cause, then see if relaxation of the nerve can be obtained by a movement of the joints above and below the seat of nerve section. In the sciatic, coaptation may be effected quite easily with the knee flexed, when separation by a considerable distance would be the result in the extended position ; in such a case the nerve is sutured with the knee flexed, and the flexion position is maintained until the wound is healed, after which the limb is gradually extended and the nerve stretched without harm. This is also the case with the median and musculospiral in the arm by flexion of the elbow, and with the median and ulnar in the forearm by flexion of the wrist. Flexion or extension of the elbow has little effect on the ulnar in the arm. In the case of the median, ulnar, and musculospiral in the arm, adduction of the arm causes relaxation. This is not so noticeable in the musculospiral on the outer aspect of the arm, where the limb is adducted when the nerve is being exposed ; but in the case of the median, ulnar, musculocutaneous, and musculospiral in its upper part, the limb may be postured for the operation in a position of abduction, even to a right angle ; this should be remembered if any difficulty of approximation arises, as the operation can be finished with the limb adducted, and thereby great relaxation of the nerve trunks will be obtained. In all cases where the ends of a severed nerve are being approximated by means of flexion of a joint, it must be carefully kept in mind that no relaxation must be permitted until the wound is healed. The danger lies in an extension movement being inadvertently made by the assistant who is holding the limb in the flexed position ; and it is necessary to watch that this is not done, or the nerve ends may thereby be torn asunder. When the brachial plexus is being dealt with above the clavicle, relaxation of the nerve trunks is brought about by raising the shoulder and abducting the head on the side of operation ; this may enable a gap to be bridged and a suture to be tied ; the position must, of course, be maintained by an appropriate splint throughout the healing of the wound.

In the event of the necessary relaxation not being thus attained, stretching of the nerve trunk should be tried ; but this should not be done until it is ascertained that less forcible methods fail, as it is a good principle in all operations on the nerves to use as little force as possible, and to conduct every procedure with the utmost gentleness. But the ends must be induced to meet if possible.

In stretching the nerve trunk, the method of procedure is to grasp the nerve with a piece of gauze, and make steady traction, avoiding any sudden movement, and being most careful not to allow the grasp to slip along the nerve : this is harmful from the irritation which it causes by damaging the surface of the perineurium, with the further possibility of dense adhesions forming along the nerve trunk. If the traction is excessive, then rupture of the nerve fibres may occur, but it is astonishing how much traction can be borne without this accident. Any operator may satisfy himself on this point should he meet with a case where partial reunion has occurred in a motor or mixed nerve and some of the muscles have recovered a partial nerve-supply. Here the only satisfactory method of treatment is excision of the cicatricial segment and suture ; but in certain of these cases the reuniting segment which requires excision is so long that stretching may be necessary to effect apposition. In such conditions the application of the electrode to the distal segment will show at certain points responses in the muscles, and these can be re-examined after each stretch. It will then be found that the ordinary stretching necessary to effect considerable elongation does not rupture the fibres, as the muscles continue to give their responses. This is just what might be expected from what we know of the condition of nerve fibres in severed nerves. If a portion of a nerve trunk is excised and prepared for microscopical examination, longitudinal sections always show the fibres to follow an undulating or zig-zag course ; and if preparations are desired showing the nerve fibres running a straight course, it is necessary to put the portion of nerve on the stretch when it is fresh, and to keep it stretched while fixing. It is this undulating course of the fibres in a severed nerve which permits of so much stretching of the nerve trunk without rupture.

Stretching presents unusual difficulties in the case of the cords of the brachial plexus

above the clavicle. Many years ago, in dealing with cases of Duchenne's paralysis, which is due to rupture or cicatricial compression of the fifth and sixth cervical nerves at their junction in the plexus, I found this difficulty very great. These trunks are often fixed in a cicatrix over a considerable area, and it is necessary to work in a small space above the clavicle. Section of the clavicle would give freer access, but is a most undesirable complication of the operation. The nerve trunk, once exposed, has to be fixed while being cleared of cicatrix, and I found that when I fixed the scar with forceps while the nerve was being put on the stretch for clearing adhesions, the cicatrix became torn and finally ruptured, after which the completion of the operation was difficult. I therefore devised a nerve stretcher which I have since found of great help in suitable cases—viz., those where the ends of the nerve are united in cicatrix which, while reuniting the ends, permits no efficient conductivity, and which must therefore be excised. The instrument, as shown in *Fig.* 288, consists of a piece of thin steel cut in the shape of a cross, each arm terminating in two prongs with bulbous ends. The breadths of the arms at their terminations measure respectively $\frac{1}{4}$ in., $\frac{3}{8}$ in., $\frac{1}{2}$ in., and $\frac{5}{8}$ in. The prongs are intended to be placed astride the cicatrix, and on rotating the instrument, as shown in *Fig.* 289, the nerve is efficiently put on the stretch with no damage to the nerve itself, only the cicatrix being pressed upon, and this is to be excised before suture, at the points A and B. On stretching the nerve, the adhesions are drawn taut, and fly asunder on being touched with the knife. At the same time the distal end of the nerve is drawn up into approximation with the central. The different spacing between the prongs adapts the instrument to different lengths of cicatrix, and the bulbous ends prevent the instrument from slipping once it has grasped the cicatrix.

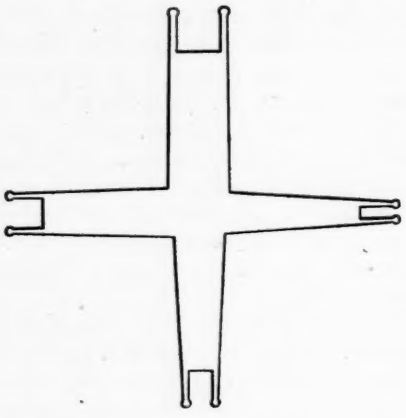


FIG. 288.

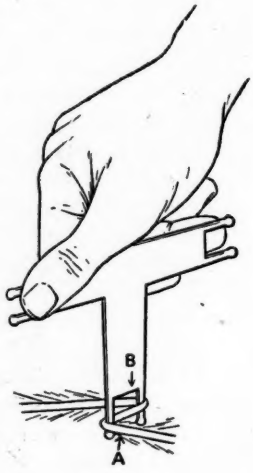


FIG. 289.

Another procedure which may be adopted to effect approximation of the nerve ends is frequently applicable to the ulnar when wounded in the arm or forearm. This depends on the fact that the ulnar is very greatly relaxed when displaced from the sulcus to a position in front of the internal epicondyle of the humerus, and wide gaps between the nerve ends can thus be overcome. It is done by making an incision over the ulna at the elbow and dissecting an anterior flap forwards. The ulnar is then made to follow a course between the muscles arising from the internal epicondyle. This is sometimes done by dissecting out the distal end of the ulnar, when the lesion is in the arm, and passing it through between the muscles into the arm; in other cases by incising the humeral origin of the flexor carpi ulnaris, placing the nerve in position, and then suturing the muscle over the nerve.

Should the nerve ends only meet with difficulty, showing much strain, it is better to fix them not quite in contact, rather than that the ends should be overstrained. In such cases good results are obtainable in spite of the fact that the approximation has not been absolute.

But there are cases in which no possibility of any reunion can be entertained, so great is the distance between the ends. Here the question of implantation or of grafting will arise, both of them procedures fraught with difficulties. It has been proved that one nerve can take the place of another, and enable function to be carried on; but the result is never up to the normal standard and is inferior to that of reunion. It has been proved also

that a portion of nerve when excised and implanted under the skin in another part of the body is not absorbed, but remains as a piece of nerve. Two nerves like the median and ulnar, one only of which has suffered a considerable loss, may be taken as an example. The sound nerve may be incised transversely, to the extent of about a third of its thickness, at two points separated widely enough to permit the central and peripheral ends of the damaged nerve to be stitched in without tension. It is possible that the fasciculi cut may be mainly sensory fibres, but that should not matter, as they are merely wanted to connect the two ends of the damaged nerve, and ought to serve this purpose equally well whether sensory or motor. It would be different in the case of an anastomosis, say, between the damaged facial nerve and the sound spinal accessory nerve, for there the central end of the facial is not available, and therefore the entire spinal accessory must be cut across to give a share of all the motor fibres. The same would apply to the principle of anastomosis performed in any nerve. The objection to the method is the cutting across of sound nerve fibres; but this is necessary if the method is to have a chance. The plan advocated by some of making a longitudinal incision in the sound nerve is, of course, quite useless, as it sections very few—a quite negligible number—of sound nerve fibres, and consequently there is nothing available for the new supply.

In the event of complete section of the nerve, the next step in the operation is to 'freshen the ends' preparatory to suture. This term, which is frequently used, is apt to give rise to a misconception as to what is to be done. The word 'freshening' would indicate the removal of the surfaces in a wound so as to prepare the way for the union of fresh surfaces; but in the case of the ends of a nerve which has been divided and has not reunited, or which has reunited by a cicatrix which does not conduct nerve impulses, the freshening required is the removal of all new formation, whether neuroblastic or fibroblastic in origin. In all cases it is most essential to see the normal appearance of the fasciculi in the nerve section, and slice after slice must, if necessary, be cut from the nerve end until this is attained, not only in the central but also in the peripheral end. The appearance is usually typical—the fasciculi projecting out from the perineurium in the form of small cylindrical processes (*Fig.* 290). When this is seen, all is satisfactory as far as the nerve end is concerned. Sometimes, however, the appearance is slightly different, and the fasciculi appear larger, do not project beyond the surface, and have a glairy look; this is due to œdema, and is also quite satisfactory. Sometimes one is tempted to stop the slicing process before these appearances are seen, because of the difficulty in getting the two ends to meet; but the temptation must be resisted, for if nerve ends which have been inadequately prepared are united by suture, the result cannot be promising.

FIG. 290.

Bulbous ends are formed partly of cicatricial tissue and partly of young nerve fibres which have developed outside and beyond the old neurilemma sheaths, and are therefore disposed tortuously. It is not safe to reunite a nerve trunk by means of the bulbs; some result might be obtained in this way, but it is apt to be imperfect; the connective-tissue element in the bulb may contract and interfere with the conductivity. It is therefore right to remove the bulbs entirely.

Where a severed nerve is joined by means of a cicatrical segment blocking the passage of impulses completely or incompletely, it must be cut out, the exact point of excision above and below being determined by the slicing process until the fasciculi are exposed.

Having prepared the ends, the next question is how best to suture them, and what material to use. Since it is necessary to leave some foreign matter at the seat of reunion in the form of a suture, the important points are to use the material which will cause the least irritation, and to use the smallest possible quantity of it. The idea of enclosing the ends in a membrane to prevent interference with the process of regeneration from the surrounding fibroblasts is not new, having been employed by Vanlair many years ago; more recently Cargile membrane has been largely used for this purpose. The great objection, however, to such procedures is that the foreign material left at the seat

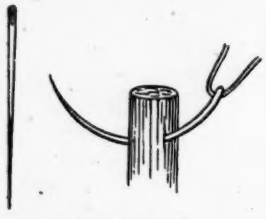
of suture is considerable, and requires either to be absorbed or encapsuled; both of these processes are accompanied by considerable reaction, and this may result in new formation of connective tissue which may prevent the desired result by its contraction.

Numerous or too thick sutures are objectionable for the same reason, and are quite unnecessary. The nerve ends can be quite sufficiently coapted by a single fine suture, passed once through each end, and tied not too tightly, but sufficiently to hold the two surfaces in apposition (*Fig.* 291). The other method is that of suturing the perineurium only, several sutures being placed round the nerve so as to coapt the two ends exactly without passing through the portion of the trunk transmitting the nerve fibres. The objections to the perineural suture are that more material is left at the seat of suture, and that although the periphery is closely coapted, the two surfaces bounded by it are not so well held together as with a through-and-through stitch, and may be separated by blood-clot as shown in *Fig.* 292.

FIG. 291.

FIG. 292.

The amount of damage to the nerve fibres caused by a single through-and-through stitch is very trivial, and can be reduced to a minimum by the use of the special needle represented in *Figs.* 293, 294. This needle is curved, and to the extent of one third of its length from the point is flattened from side to side with a cutting edge on concavity and on convexity. About one third of its length from the point the needle gradually increases in breadth so as to permit the eye to be made in the same plane as the two cutting edges. Many needles have the eye passing in the opposite direction to the cutting edges, and this makes a great difference in the amount of damage which the thread inflicts on the nerve during the passage of the threaded eye. The nerve is transfixed as shown in *Fig.* 294. The flat needle cannot wound many fibres in its passage, and the loop of suture is so placed, owing to the direction of the eye, that it easily takes the slit made by the needle.



FIGS. 293, 294.

The thread employed in the suture may be absorbable, or one which requires to be encapsuled. If the former, then the finest catgut should be chosen, and prepared by some method which renders it sterile and absorbable in fourteen days. I have always employed, except in experimental work on small animals, chromicized catgut, specially prepared for this purpose by my staff.* In the case of extremely fine nerves in experimental work on monkeys, where the finest catgut would be relatively too thick for suture of the nerve without causing too much damage, I have used horsehair, and found it very successful. The nerves reunited functionally, and at the physiological examination the horsehair was found encapsuled at the seat of suture. It is a perfectly safe suture, and could well be used instead of catgut in any case.

There now only remain a few general considerations. Nerve regeneration, whatever be its nature, finds without any doubt the greatest bar to its successful accomplishment in the development of the fibroblasts into fibrous tissue. This has not only an antagonistic effect on the process of regeneration, but a destroying effect after that process is accom-

* The raw catgut is loosely wound on reels made of glass rods bent into rectangles, one piece only being put on each reel so as to allow the different liquids free access to the gut. On these reels it is soaked in ether for twenty-four hours to remove fat, and then dried in air. It is now soaked in 0·1 per cent aqueous solution of chromic acid for three days, and then washed in running water for two or three hours to remove all unfixed chromic acid. It is next boiled in alcohol in an open glass tube for one hour—not with any intention of sterilizing, but so as to dislodge all the air-bubbles from the interior of the gut thread—and then allowed to cool in the alcohol. It is these air-bubbles which make catgut so difficult to sterilize, as they prevent the antiseptic from getting access to the organisms in the portion of the gut lodging the air-bubble. The gut is finally soaked in 20 per cent carbolic glycerin for a few days, and preserved in the same fluid till required for use. Before use, the antiseptic is removed by soaking the gut in alcohol.

plished. In operative work, therefore, everything which tends to produce scar formation militates against success. Aseptic technique of a high standard is essential if good results are to be expected. It is no proof to the contrary if a case of nerve suture has become septic and yet a good result has followed: it will certainly be a very exceptional occurrence. Therefore the greatest care to prevent the entrance of organisms into the wound is a rule the importance of which cannot be overestimated, in order to leave as little sterilization work to be done by the tissues as possible, and thus require the minimum of reaction in the wound. It is true that many cases of subcutaneous rupture of nerves are met with in which no recovery of function takes place, although no bacteria have been at work at the seat of rupture; but in these cases the failure to unite functionally is due to the same cause—namely, the intensity of the reaction, leading to the formation of connective tissue which contracts and prevents conductivity in any nerve fibres which may have regenerated. This reaction is not due to micro-organisms, but to the trauma which caused the rupture and the processes which follow thereon.

For the same reason it is essential that all manipulations of the nerve throughout the operation should be of the gentlest. The knives should be as sharp as possible, all nerve slicing should be done with a fresh knife which has not been used since it was sharpened, and the slicing should be performed with a gentle sawing movement so that the fibres sustain as little damage as possible. The less force required to effect all the procedures, the more likely is there to be a good result. This is the chief reason why it is desirable to use a tourniquet, applied after the limb has been emptied of blood as completely as possible, so that the procedure shall be bloodless. The bleeding is often considerable in these cases, particularly if there has been much scar formation, and the constant swabbing which is required to keep the parts clear, and the application of hæmostatic forceps and ligatures, must considerably irritate the parts in which the newly-sutured nerve is to lie. If the limb is properly emptied of blood, the whole procedure may be carried out in a much shorter time; and there is no need for swabbing, and consequently much less trauma. Before the suture is completed, if there is any chance of damage having been done to a vessel of any size, the tourniquet may be removed, the vessels ligated if necessary, and then the nerve operation completed and the wound closed; but in the absence of this exceptional circumstance, the best way is to close the wound, apply the dressing firmly, and then remove the tourniquet. Any blood that oozes from the capillaries escapes into the dressings and does no harm, and it is a very rare circumstance for there to appear more than sufficient to stain the innermost dressing.

SHORT NOTES OF RARE OR OBSCURE CASES.

A CASE OF GUNSHOT INJURY OF MECKEL'S DIVERTICULUM.

By Major GORDON TAYLOR, R.A.M.C. (T.C.)

Pte. W. G. E., was admitted into a casualty clearing station in the spring of 1918 with a shell wound of the right buttock, but with obvious signs and symptoms of a penetrating injury of the abdomen; he had been hit six hours before.

The missile was found to have entered the right buttock, and to have opened the right side of the perineal portion of the rectum about two and a half inches from the anus; it had entered the right infero-lateral and extra-peritoneal wall of the bladder, and emerged from the peritoneal surface of this viscus at the junction of the superior surface and the base. The track between the rectum and the buttock was laid widely open, and the sphincter divided. The wound of the peritoneal surface of the bladder was excised, and the edges were sutured with catgut; the cavum Retzii was drained with a piece of rubber sheeting.

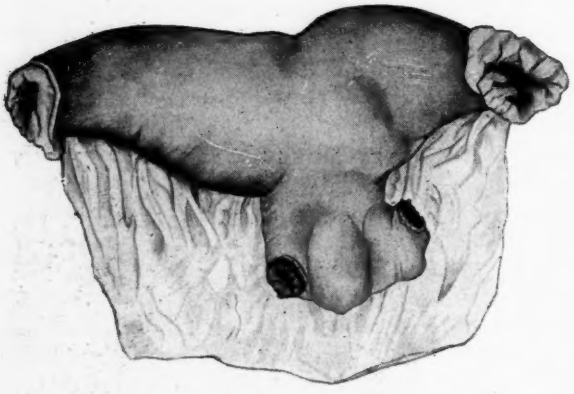


Fig. 295.

There were sixteen perforations of the ileum, and several holes in the mesentery; two of the wounds in the bowel were along the mesenteric attachment. There were also two small wounds in a Meckel's diverticulum which was present. It was deemed necessary to resect the damaged portion of the ileum, and the resection was extended downwards so as to include the portion of bowel to which the diverticulum was attached; three-and-a-half feet of small intestine were removed, and an end-to-end junction was made. The Meckel was rather under one inch in length, and somewhat tri-lobed at the end; the missile had perforated it near the distal end (*Fig.* 295). In spite of the severity of his injuries, the patient made a good recovery, and was evacuated to the base eleven days after operation; five weeks later a satisfactory account of his progress was obtained.

The injury cannot be a very common one, and the case therefore seems worthy of record.

I am indebted to my friend and colleague, Captain H. T. Andrew, R.A.M.C., for the sketch which accompanies this note, and to Colonel L'Estrange, R.A.M.C., for permission to publish the notes of the case.

A CASE OF CONGENITAL DEFECT OF THE THORAX, WITH SPRENGEL'S DEFORMITY.

By Captain HAROLD BURROWS, R.A.M.C. (T.F.)

The patient, age 20, is a private in the machine-gun corps. In peace time he is a grocer's assistant. All his life he has noticed a bulging of the left chest whenever he coughed,

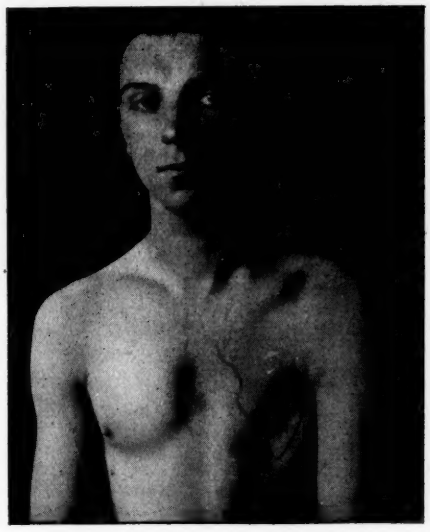


Fig. 296.—Patient when at ease. Outlines on chest demarcate boundaries of defect in chest wall as elicited by palpation and verified by radiogram.

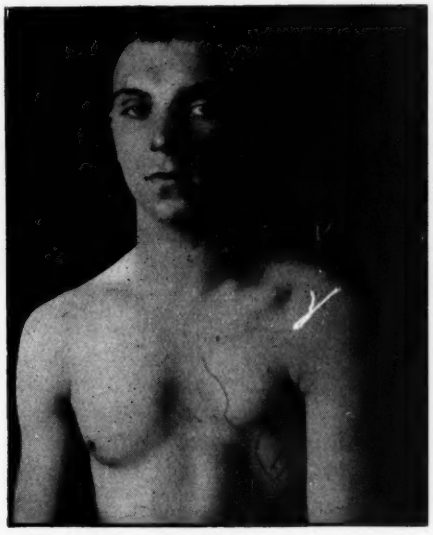


Fig. 297.—Shows patient while making a forced expiratory effort.

but he has not experienced any particular inconvenience from this. He was able to undergo his course of training as a soldier, and made no complaint on account of his deformity, though he says he has always found it difficult to carry his pack.

On examination of his chest, it was found that the left anterior chest wall is defective, considerable sections of the second, third, and fourth costal cartilages and ribs being absent (*Figs.* 296, 297). The remaining ribs are normal in number, position, and shape. The pectoralis major on the affected side is ill-developed; otherwise no defect of muscle or nerve is to be observed. The left nipple is smaller than the right, and is situated at a higher level. A hernia of the lung is visible when the patient coughs.

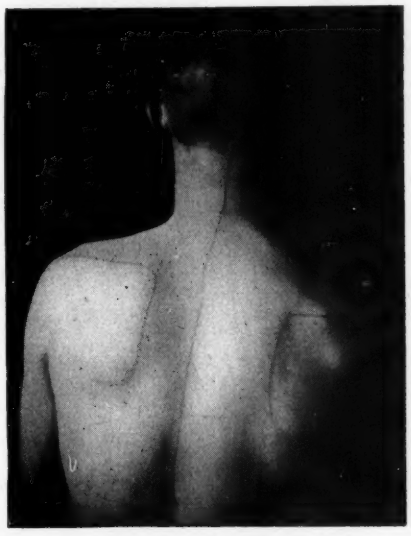


Fig. 298.—Back view of patient.

On viewing the patient from behind, the left shoulder is seen to be hunched up, while the left scapula is slightly smaller than the right, nearer to the vertebræ, and at a higher level (*Fig.* 298). The scapular muscles, however, appear to be well developed, though the posterior superior angle of the scapula is more clearly noticeable on the left side than on the right. There is a lateral curvature of the spine, with the maximum curve in the dorsal region, the convexity being directed to the right.

The left chest is retracted to a remarkable degree, as shown by the accompanying cyrtometer tracings (*Figs.* 299, 300, 301).

My colleague, Lieutenant S. Owen, informs me that there is no dextrocardia or other visceral abnormality to be found, nor are there any congenital defects other than those already mentioned

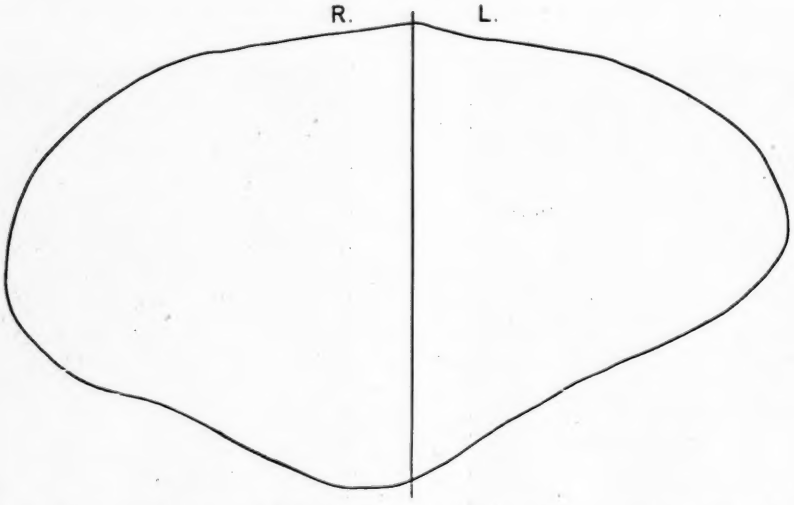


FIG. 299.—Cyrtometer tracing at level of first interspace. Circumferential measurement: R = 20 in. L = 18½ in.

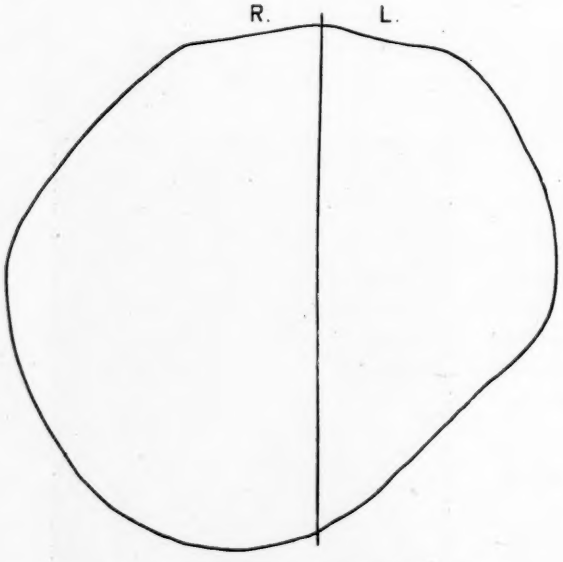


FIG. 300.—Tracing at level of fourth rib cartilage. R = 18 in. L = 14¾ in.

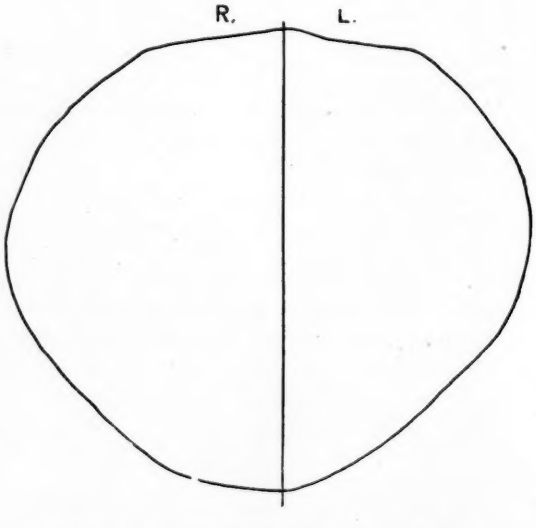


FIG. 301.—Tracing at level of tip of eighth cartilage. R = 15¾ in. L = 11½ in.

The case is remarkable on account of its rarity, and also because the patient suffered so little inconvenience from his abnormalities.

I am indebted to Dr. F. Brigham, of Harvard University, for the photographs.

A CASE OF TORSION OF THE APPENDIX.

By JOHN E. PAYNE, Torquay.

There appears to be no record of this condition in the many works on the appendix; the following case may therefore be of interest.

Mrs. Z., a nullipara, age 37, had always suffered from constipation, the bowels sometimes not acting for seven days.

Ten years ago she had a sudden attack of abdominal pain and faintness which lasted for about six hours. There was no vomiting, and the pain gradually passed off. She was seen by a doctor, who diagnosed appendicular colic. Following that attack, the patient suffered from indigestion for several months, and since then has frequently had attacks of pain and soreness in the right iliac fossa on the second day of the menstrual periods. Two years ago there was another attack of pain lasting for thirty-six hours, associated with vomiting but not in relation to menstruation. This was diagnosed as a bilious attack. For the last month the indigestion has again been bad, with some abdominal pain, sickness, and a sense of fullness in the epigastrium.

Fig. 302.

On Monday, March 13, 1916, while travelling in a train, she was seized with sudden pain in the epigastrium after lunch. She vomited several times, but the pain continued and was of a colicky nature. At midnight the pain suddenly shifted to the right iliac fossa and became continuous.

The following day a doctor was called in; he ordered enemata, and three were given, with very copious results. On the 15th I saw the patient and operated the same evening.

On opening the abdomen through the right rectus incision, the appendix was found pointing downwards and slightly outwards in the right iliac fossa. It was quite free except for a slight recent adhesion from the extreme tip to the iliac fossa. On examination it was found to be twisted, and it took three complete turns to unravel it (*Fig.* 302). The appendix distal to the narrowing caused by the twisting was gangrenous, and the meso-appendix dark and swollen. The appendix was removed, and the abdomen drained through the original incision. The temperature and pulse became normal on the third day, and the patient made an uneventful recovery.

Remarks.—The appendix was $2\frac{3}{4}$ in. long, and contained fæcal material. It seems most probable that the previous attacks were due to a 'constipated appendix,' and that the torsion resulted from irregular peristaltic movements on the part of the appendix itself.

REVIEWS AND NOTICES OF BOOKS.

War Surgery of the Abdomen. By CUTHBERT WALLACE, C.M.G., F.R.C.S. Eng., M.B., B.S. Lond. Surgeon, St. Thomas's Hospital; Lecturer on Surgery in the Medical School; Consulting Surgeon, British Armies in France. Pp. 152; 26 illustrations. 1918. London: J. & A. Churchill. 10s. 6d. net.

No chapter of war surgery has been more dramatic than that dealing with abdominal wounds; the complete reversal of the practice of previous campaigns, the equipment of units for the performance of operations calling for the highest surgical skill within the battle zone, and the saving of nearly 50 per cent of those so wounded, were all accomplished within a year of the commencement of the war. This, perhaps one of the most difficult problems of the many that presented themselves to the surgeon, was one of the first to be settled. Before even the pathological processes underlying the evolution of an ordinary wound of the soft parts were understood, or fractures received more than casual attention, results were being attained in the treatment of penetrating wounds of the abdomen that have been but little improved since.

This rapid success must be attributed to the high state of evolution of abdominal surgery in the years immediately preceding the war, to the facilities for rapid transport by motor ambulance, and to the stationary warfare that became established after the first few months.

Wallace's book is chiefly based on cases operated on during the period July, 1915, to December, 1916; it embraces the work of many surgeons carried out at different hospitals on a wide sector of the front, and includes both quiet periods and times of heavy fighting. The many statistical tables built up from a large number of cases under such varying conditions form a valuable historical record, and afford a standard by which to judge the results of future work.

The operative mortality (all cases) is remarkably uniform throughout successive periods from July, 1915, to September, 1917, varying from 53·9 per cent to 51·3 per cent. It is interesting to observe, however, that whilst only 60 per cent of cases (310 out of 511) were operated on in the first six months, 76 per cent (640 out of 889) were so treated in the last nine months; this, together with the general speeding up of evacuation, which has resulted in more cases reaching the surgeon alive, means a very real improvement in results which the tables hardly bring out.

The rapid evacuation of these cases from the firing line, early operation, and retention in the unit in which they are operated on for some days after operation, are the three essentials for success. They are purely administrative problems, and any or all of them may be rendered impossible by the exigencies of the military situation. Speaking broadly, the arrangements of our French and Belgian Allies have been much the same as our own in dealing with these cases. More and more the attempt has been made to bring the surgeon to the wounded rather than carry the wounded to the surgeon. Perhaps this has been overdone; certainly, with the onset of more open warfare and the increased use of long-range artillery, there has been a reaction since 1916. The author is opposed on the whole to the advanced operating centre as the most suitable unit with dealing with these cases, especially during periods of heavy fighting, and prefers direct evacuation to a casualty clearing station in spite of the longer journey entailed: the smaller unit is liable to be swamped, because cases accumulate, and thus defeat the attempt to secure early operation. Certainly, with the diversion of heavy and lightly wounded cases to different casualty clearing stations and the pushing up of clearing stations nearer to the front line than was at one time the case, the advanced operating centre has to a large extent outlived its usefulness; nevertheless it played an important part in the evolution of abdominal war surgery.

From a clinical point of view these cases present many difficult problems even to the surgeon skilled in abdominal work in civil life. Wounds of the hollow viscera, wounds of the solid organs, penetrating wounds without visceral injury, and parietal wounds, may present a similarity of symptoms that makes an exact diagnosis at times almost a matter of guess-work. Under these circumstances an exploratory incision is frequently the wisest and safest course to take, and one rarely has cause to regret it. Hæmorrhage is the chief cause of the high mortality, and its persistence demands that intervention be carried out as early as possible. Pre-operative measures to combat shock are of the greatest importance, and only experience can enable a surgeon to select the proper moment to operate on a patient who is reacting to this treatment; in the same manner, when casualties are heavy, the greatest skill and experience are necessary to select those cases most likely to benefit by operative interference.

The author is to be congratulated on having produced a book, not only of interest from the point of view of what has been achieved, but also of considerable assistance to those who are at present engaged on the problems with which it deals.

Blood Transfusion, Hæmorrhage, and the Anæmias. By B. M. BERNHEIM, M.D., Instructor in Surgery, the Johns Hospital University. 8vo, illustrated. 1917. Philadelphia and London: J. B. Lippincott Co. 6s. net.

THIS book records a great deal that is of extreme importance to the physician as well as the surgeon, but it is unfortunate that owing to the author having had to depart for the Johns Hopkins Base Hospital Unit he was deprived of opportunity for its final inspection and revision. We feel certain that further deliberation would have led to the deletion of some of his suggestions.

The author discusses in detail the phenomenon of bleeding, and deals with many of the methods useful in differential diagnosis between hæmorrhage and shock. He is of opinion that transfusion is far from a serious undertaking, and that perhaps it is wiser to err by giving a transfusion when recovery might have occurred without this procedure, than run the risk of the patient passing into a state from which recovery is very doubtful. We have no hesitation in saying that anyone who has carried out a large number of transfusions will agree with Bernheim on this point.

The author suggests that transfusion is indicated in seven conditions: (1) actual hæmorrhage; (2) in connection with surgical operations; (3) for the relief of hæmorrhagic conditions; (4) blood disease; (5) infections; (6) poisons; (7) debilitated conditions.

He alludes to the dangers of transfusion, and points out how difficult it is to estimate the mortality following transfusion; we feel that this is of little importance unless the details of the methods adopted are recorded along with the reason for giving the transfusion. Several deaths referred to, are recorded by surgeons, and were due to unsuitable donors having been selected; that is to say, donors whose bloods belonged to different groups from that of the patients; this led to hæmolysis and agglutination. Six fatalities are alleged to have been due to causes other than hæmolysis: four to acute dilatation of the heart, and two to questionable anaphylaxis. With all deference, we express doubt as to these causes in the six cases. The symptoms of anaphylaxis and of dilatation of the heart simulate very closely those produced by agglutination of red corpuscles upon injecting unsuitable blood.

The importance of the suitability of the blood is emphasized by Bernheim in the following passage: "Thus the absolute necessity for preliminary tests must be apparent to all. When blood transfusion first came into vogue it was the common thing to poke fun at hæmolytic tests; many men had done numerous transfusions without tests and without the sign of hæmolysis or other trouble, so that the feeling arose that its occurrence was a remote possibility and therefore one to be ignored. But it was not long before cases of hæmolysis began to make their appearance, and with the growing popularity of transfusion they became more and more common, until a number of fatalities occurred, and a distinct change of sentiment concerning the importance of the complication was noted."

With this we agree, and think that if Bernheim had revised the book he would have deleted the latter part of the following passage: "In others, 50 c.c. a day for ten days may be sufficient, or 100 c.c. every other day, the idea being to use blood as a stimulant or perhaps even for its nutritional value, instead of giving it in bulk as is now customary. A husband, brother, or sister could give up these insignificant amounts of blood daily, or every two or three days, without inconvenience or harm, and it may even be proved that hæmolytic and agglutination tests will prove superfluous, since the amounts given would be so small as to be incapable of causing serious trouble."

The author refers to one death due to sudden agglutination in a case which, as far as the operator knew, was being transfused with the blood of the correct group, but subsequent observation showed that agglutination occurred when the bloods of the donor and patient mixed. Although we have never seen death result from this cause, we know of a case in which transfusion had to be stopped for a similar reason. The donor—who was believed to belong to *Group* 4, and who had given his blood with benefit to a patient suffering from pernicious anæmia, whose blood also was of *Group* 4—was used three months later as a donor to a *Group* 4 patient. Symptoms developed after a small quantity of blood had been injected, which led to the transfusion being stopped, and on re-examining the donor's blood it was found that he belonged to *Group* 3. Whether under any circumstances an individual can change from one group to another is a matter of interest, but at present evidence seems to point against it.

The importance of the donor and the patient being of the same group having been insisted upon, it seems rather a pity that Bernheim has relegated to the appendix methods of determining to which group an individual belongs, and the methods of deciding the compatibility of two bloods.

It is difficult to agree with the statement that "by many men it is considered quite unnecessary to carry out the group method of testing, a more direct means of attaining the same end being that of testing all prospective donors directly against the recipient until a suitable donor is secured," except when the medical man is but rarely called upon to carry out a transfusion. By classifying the prospective donors a list may be prepared, and one of a suitable group may be procured with minimum delay. Chance should be excluded whenever possible, and it is always within the limits of possibility that half a dozen or more donors would have to be brought to the patient, in order to select one belonging to the same blood group.

Bernheim refers to the danger to the donors, and states: "I have never lost a donor, nor have I heard of a person losing his life by giving his blood in a transfusion." This we can believe most readily. In the majority of cases, donors assert that they feel better after giving 700 c.c. of blood, and on the seventy-five occasions upon which we have observed the transfusion of blood,

we have never seen an untoward symptom. Bernheim is averse to giving any drug to the donor; we have reason to believe that a cup of strong coffee is of advantage. The author is not in favour of using the same donor time after time. Some have done so a dozen times or more, in a case of pernicious anæmia, with the idea that, by bleeding, a hormone might be formed which would stimulate the blood-forming tissues.

The methods of transfusion are given in considerable detail, and the advantage and disadvantage of each method carefully criticized. This part of the book will prove invaluable to those who are novices at transfusion, and if it had been in existence years ago it would have saved many practitioners much time and trouble. Lindeman's method is given in detail, but the citrated methods find favour in the eyes of the author; and no doubt, when blood is given simply to replace that which has been lost, the citrated method is as convenient and as satisfactory as any other.

In the chapter dealing with transfusion for pernicious anæmia, the author is disconcerting by confusing the argument for and against multiple transfusions with the question of splenectomy. We gather from the chapter that in no case which has come under his observation have transfusions been persisted in to the extent which experience has shown us is necessary. We have had under observation a case in which fifty transfusions have been carried out in two years, in order to maintain the patient's red cells above two and a half million per cubic millimetre. Bernheim concludes that in hæmorrhagic diseases, and in leukæmia, transfusion is of comparatively little value; but in these cases, too, perseverance is conspicuous by its absence.

The book is well illustrated, and the diction clear, although the author is too lavish with epithets. To-day few medical men can afford to remain ignorant of the facts recorded in it.

The Action of Muscles, including Muscle Rest and Muscle Re-education. By W. Colin Mackenzie, M.D., F.R.C.S., etc. 8vo. Pp. 267 + xvi. Illustrations 99. 1918. London: H. K. Lewis & Co. Ltd. 12s. 6d. net.

This book on the action of muscles is evidently the result of much original investigation. Dr. Colin Mackenzie is a devout follower of the teachings of Hugh Owen Thomas, and shows a keen appreciation of the work of John Hunter, Charles Bell, Duchenne, Haller, and Cowper, who all devoted much time to the study of motion.

A plea is made for wider recognition of certain principles in the treatment of muscle injuries and paralysis. The importance of physiological rest is emphasized, and simple methods of its application for each form of nerve lesion are illustrated. Re-education of muscle function follows the lines found effective over a long experience of successful treatment of infantile paralysis. The position of the different joints from which re-education should be commenced is clearly defined. This allows early volitional control to be established without the risk of overstrain.

The chapters dealing with the specialized action of muscles and their opponents explain, on a rational basis, many of the deformities now common in military surgery. The work of the modern physiologist and anatomist on the action of muscles is presented throughout in a form which makes it readily available to the clinician.

This book would be welcome at any time, but is especially so just now, when restoration of function in limbs is such a huge problem for the Empire. It should be widely read.

Laboratory Methods of the United States Army. *Medical War Manual No.* 6. Compiled by the Division of Infectious Diseases and Laboratories, Office of the Surgeon-General, War Department, Washington, D.C. 1918. Philadelphia and New York: Lea & Febiger.

This little book will be useful chiefly to research students and workers in hygiene laboratories. The sections dealing with the chemical investigations of urine, blood, water, and milk give well-selected methods, which are clearly described. The same can be said of some of the special bacteriological methods, e.g., the determination of types of pneumococcus, though the differentiation of the coli-typhoid group of organisms and the estimation of agglutination units could be stated more fully and more clearly.

The general rules obtaining in a laboratory, and the recipes for stains, solutions, and bacteriological media, etc., are sufficient, concisely set out, and should be valuable to the laboratory attendant. In a subsequent edition these could be amplified with advantage by the addition of some of the other useful media, e.g., Drigalski nutrose agar, whey agar, etc.

The section on clinical pathology is quite insufficient, and will be of no practical help to the medical officer engaged in the routine laboratory work of a field or general hospital.

The qualitative examination of urine includes no simple tests for recognizing the presence of blood; no reference is made to renal casts and their varieties; the detection of bilharzia, not infrequently present in troops who have served in Egypt, is not considered; the account of the varieties of crystals found in urine is very meagre.

In the few lines dealing with the examination of the blood there is no mention of the routine estimation of hæmoglobin percentage and colour index by means of a hæmoglobinometer. The

paragraph headed 'Differential Count' deals only with the preparation of blood films; the varieties of leucocytes to be differentiated are not even mentioned.

No mention is made of the varieties of malarial parasites commonly met with in routine work.

In the examination of fæces the differentiation of amœbæ and the presence and significance of cysts are not considered.

Examinations of the throat and mouth are restricted to diphtheria; no reference is made to Vincent's *B. fusiformis*, spirochætes, oidium, streptococci, etc.

On page 164, 'Simple Diagnostic Table for Gram-negative Bacilli' contains two serious errors. *B. coli communis* does *not* liquefy gelatin, and *B. paratyphosus* forms acid and gas with dulcite. Two paratyphoid bacilli, *B. lactis aerogenes*, and Morgan's bacillus are omitted from the table.

This booklet is disappointing. It has apparently been devised by an expert chemist, and to the chemical research worker it may possibly be a handy guide, though as a rule he will be supplied already with the text-books on his subject. For the laboratory attendant there are many and better-equipped manuals. To the clinical pathologist the book has no value. The table of contents is not a satisfactory substitute for a good index.

Generally, it would seem that an attempt has been made to cut a uniform for the use of several very different individuals, and the result is an unfortunate misfit.

Modern Urology: in Original Contributions by American Authors. Edited by Hugh Cabot, M.D., F.A.C.S., Boston, Massachusetts. Vol. I, pp. 744, 368 engravings and 7 plates; Vol. II, pp. 708, 264 engravings and 10 plates. Philadelphia and New York: Lea & Febiger. $14 net.

Modern urology in a "correlated set of monographs" by twenty-nine American contributors, each writing with the authority of a specialist, given 1452 pages in which to state their views untrammelled by the exactions of the systematic text-book, promises a feast of knowledge in this branch of surgery which should attract even the jaded surgical appetite of 1918. Let us see what the twenty-nine surgeons make of their opportunities.

Volume I opens with an historical sketch of genito-urinary surgery in America, by F.S. Watson, in which are brief notes of some of the more prominent men in the field of American urology, including one of Watson himself from the pen of Keyes junior. They are a distinguished company, among whom not the least striking is Bigelow. Here also is related the progress of urinary surgery in America; and surgical instruments and devices introduced by American surgeons are described. Then follows a careful and very concise account of the cystoscope and its use, by Leo Buerger: one of the best articles in the book.

Bransford Lewis has a chapter on methods of diagnosis, in which it is interesting to note a plaint as to the many failures in diagnosis that he sees, a note that might well find echo in this country. With this article (for it is incomplete as it stands and is none too full) should be read that of Dodd on *x*-ray diagnosis, and one by Geraghty in Volume II.

Geraghty's article on tests of the renal function is, as we would expect, clearly written and authoritative. The study of these tests has progressed rapidly in surgical work, and the subject possesses a voluminous literature. Geraghty's article helps to brush aside much that is superfluous and unnecessary in this difficult subject. The author rightly devotes a large part of his article to the phenolsulphonephthalein test which he and Rowntree introduced, and which is now accepted generally as the most reliable and easily applied of all the tests. No article has appeared in English medical literature on this subject, and Geraghty's synopsis will be welcome.

Corbus, writing on syphilis of the genito-urinary organs and on genital ulcers, suffers from the disability of having to deal with only a small section of an important general disease. Apart from this, the chapter is an excellent review of the subject, and there is a fairly complete bibliography. Strangely, he omits to mention congenital syphilis affecting the kidney, which has been described in this country and elsewhere.

A complete and instructive account of the diseases of the female urethra is written by Osgood.

Keyes junior deals with stricture of the male urethra in thirty-two pages. He looks upon the intensity of the gonorrhœal urethritis, not its chronicity, as the cause of the stricture. His statement that "gonorrhœal stricture is but a cicatrization of the pathological process that causes chronic anterior urethritis" is somewhat nebulous, but when he comes to treatment it is evident that his views in regard to the prevention of stricture by the intelligent treatment of chronic urethritis of the infiltrating type are on sound and generally accepted lines.

This author's views in regard to operation for stricture differ from those held in this country. Operation is reserved for cases where dilatation has failed. So far, so good; but note the nature of the operation. "For strictures of the pendulous and scrotal urethra, internal urethrotomy upon the roof of the canal. For stricture of the bulbous urethra, external urethrotomy." The reason for this selection of the operation according to the position of the stricture is not stated. The lines on resection of the urethra at the end of the article are disappointingly short and uninstructive.

The article on tuberculosis of the genital tract by Barney is excellent in its breadth of

view and evidence of wide reading, and in its detail. The paragraphs on prognosis are full of interest, and obviously based on careful work and wide experience.

Prostatic obstructions is the subject of an elaborate article by Pilcher. Obstruction from causes other than gross enlargement of the prostate receives but scant notice, and a more detailed account would have enhanced the value of the article. The author rightly insists upon the importance of thorough preparation before operation. He prefers prostatectomy in two stages in practically every case of glandular hyperplasia of the prostate. The three reasons he gives are entirely unconvincing. A small percentage of cases are selected for the two-stage operation by all surgeons experienced in urinary work. To subject every patient to the anxiety and discomfort of two operations, and to prolong the period of surgical convalescence by a week or ten days, appears to be an unnecessary infliction and not justified by results. The most striking feature of this article, next to the absence of any reference to the English literature on the subject of the operation, is the complete suppression of statistics giving results of the operation. The discussion of after-results, measured by work published by other surgeons, is also disappointing. Impotence appears to be confused with sterility, for it is attributed to "injury to, or removal of, the ejaculatory ducts."

Young's contribution is a very careful article on cancer of the prostate. The symptoms are considered in much detail, and this part of the article is specially valuable. The operative treatment, including the author's radical operation, is fully described, and the use of radium shortly considered. Five out of ten cases submitted to the author's radical operation were probably cured, but as these represent the whole of the operations performed in about fourteen years, the cases suitable for this operation are obviously very few.

Instructive articles by Kretschmer, Lower, Hagner, and Caulk do not call for detailed comment.

Cabot has two important articles on stone in the bladder and stone in the kidney and ureter. His discussion of the etiology of stone is the least attractive part of these articles. It is lacking in clearness, and there is no mention of the cement substance which is generally regarded as the most important factor. The operations for stone in the bladder are very fully and ably discussed. Cabot gives, unintentionally we believe, the impression that less credit is due to Bigelow than we in this country are accustomed to give him, and he further omits to mention that the battle for litholapaxy was fought by the surgeons of the Indian Medical Service. No mention is made of litholopaxy in children, and the author does not appear to be familiar with Keegan's work. The discussion of results of bladder-stone operations is incomplete without statistics, and none are given.

In discussing the methods of closing the kidney wound after nephrolithotomy, the author looks upon the use of mattress sutures as 'wholly objectionable,' and has seen necrosis requiring nephrectomy follow their use. This statement is too sweeping. Kidney surgeons of large experience constantly employ mattress sutures without such untoward results.

Tumours of the bladder are ably discussed by Geraghty. He points out that the nature of the tumour cannot be decided in all cases by histological examination of the base. On the other hand, he rightly insists that the information derived from the examination of small portions of a bladder tumour removed by the operating cystoscope is not always conclusive.

Bentley Squire's article on anomalies of the kidney, hydronephrosis, movable kidney, and injuries to the kidney, repays perusal; but something more might have been made of the subject of hydronephrosis, and the selection of cases for operation in movable kidney might with advantage be more fully considered.

Infection of the kidney is discussed in detail by Keyes junior, and tuberculosis of the kidney is dealt with by O'Neil in an article that gives a very clear picture of the disease and an excellent summary of the treatment and the results to be expected therefrom.

The second volume closes with a carefully written account of tumours of the kidney by Binney.

The two volumes are profusely illustrated in black and white and in colour, the former being more successful than the latter. There are many fine illustrative drawings excellently reproduced, and the *x*-ray photographs are of exceptional quality. Photography has been used to illustrate some diseases and operations, and one feels a protest might be made against this form of illustration, which, except for imparting a sense of realism and providing a quite unnecessary certificate of good faith, teaches, in most cases, nothing. Most of the illustrations are original, and those borrowed are acknowledged. Young's article, however, is marred by the reproduction of three original illustrations from an English text-book without acknowledgement.

Looking back over these volumes as a whole, there is a sense of incompleteness that arises from the somewhat unsystematic nature of the book; there is the want of correlation and the redundancy that result from a number of independent authorities working in watertight compartments; there are the excursions into ancient history in some articles, the omission of which might well be excused by the title of the book; there is the robust pan-Americanism of the writing that we confess just now and then jars slightly on one outside the circle of American urologists; but taking it all in all, brilliant articles and mediocre, concise and well-weighed writing with diffuse and slovenly, the publication is indeed a notable one, and creditable to the remarkable body of men who have produced it, and to the Editor, of ancient surgical lineage, who contributed to its articles and moulded and guided its development and birth.